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WILLARD ROUSE JILLSON
DIRECTOR and STATE GEOLOGIST

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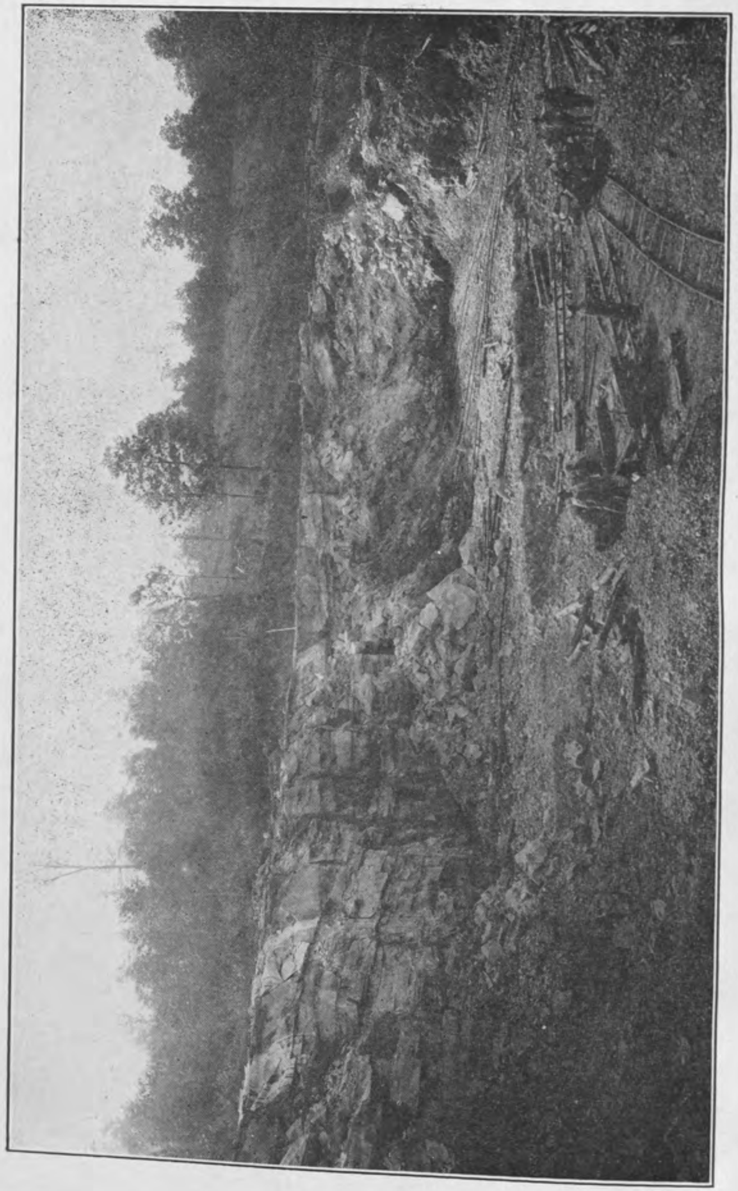
Molding Sands of Kentucky

Cement Materials of Kentucky

Geology and Coal Resources
of the
Middlesboro Basin

1927



PHOTOGRAPH BY W. R. JILLSON

A CARTER COUNTY, KENTUCKY, SAND OPERATION

This view shows the quarry and a portion of the sand reserve of the Camp Glass Co., at Lawton. The sandstone ranges from friable to soft, and is of excellent quality in this part of the State. Much of it would be useful for molding purposes.

The MOLDING SANDS OF KENTUCKY

A detailed report covering the field examination, mechanical analysis and industrial evaluation of the principal Molding Sand Deposits of the State.

BY

CHARLES H. RICHARDSON
Assistant Geologist

Illustrated With Twenty-Two Photographs and Maps

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Letter of Transmission

DR. WILLARD ROUSE JILLSON,
Director and State Geologist, ,
The Kentucky Geological Survey,
Frankfort, Kentucky.

Dear Sir:

Permit me to transmit herewith my illustrated manuscript entitled, "The Molding Sands of Kentucky."

The special field work for the preparation of this report was done during the summers of 1924 and 1925. Every county in the state known to contain molding sand was visited and the possibilities of these sands are described herein.

It is hoped that this report will contribute somewhat to the literature on the molding sands of Kentucky and prove of service to the industrial development of the state.

Respectfully submitted,

CHARLES H. RICHARDSON,
Assistant Geologist.

Syracuse, New York,
September 21, 1925.

Contents

Illustrations

Preface

The object in preparing this report on the molding sands of Kentucky is mainly to present to the general public through libraries, boards of trade, chambers of commerce, owners of foundries, etc., some information of general interest upon the molding sand possibilities of the state.

It seemed advisable to undertake the investigation of this problem because there was no definite state report dealing directly with the molding sands of Kentucky, no mechanical analyses so far as known had been made of these molding sands, and no evaluation of these deposits had been suggested to aid in a conservative estimation of the mineral wealth of Kentucky.

During the past six years, in his geologic work, the author has visited every one of the 120 counties within the state. However, molding sands do not occur in all of these counties. The 19 counties in which molding sands were found are listed in alphabetic order in this report and the characteristics of each deposit are described.

Many photographs have been taken in the field work and 20 of these will appear as half-tone illustrations in this work.

Twenty-four samples, each exceeding fifty pounds in weight, have been collected and shipped express prepaid to Professor H. Ries, Chairman of the Sub-Committee of the American Foundryman's Association, Cornell University, Ithaca, New York. for analysis, and twelve samples each exceeding twenty pounds in weight have been collected and shipped by express prepaid to Professor N. M. Fenneman, University of Cincinnati, likewise for analysis.

The author recognizes his especial indebtedness to Dr. Willard Rouse Jillson, State Geologist, for his many suggestions, to Dr. H. Ries, Cornell University, and Dr. N. M. Fenneman, University of Cincinnati, for their hearty cooperation in this work.

CHARLES H. RICHARDSON.

Molding Sands of Kentucky

MOLDING SANDS OF KENTUCKY

By Charles Henry Richardson, Ph. D.

CHAPTER I.

INTRODUCTION

The specific investigation of the molding sand deposits of Kentucky was made possible through the hearty cooperation of the Kentucky Geological Survey with a joint committee of the American Foundrymen's Association and the National Research Council. It reflects only a part of the program outlined to secure data on the various molding sand deposits of the different states and classify molding sands according to the results of the mechanical analyses made in the different laboratories cooperating with the American Foundrymen's Association. It is evident that there is need of much work on the part of such laboratories in the standardization of their results, for a given molding sand has often been reported by one foundry doing a certain type of work as highly satisfactory and by another foundry doing approximately the same kind of work as entirely unsatisfactory.

The State of Kentucky naturally divides itself into five distinct districts for investigations and descriptions of its mineral resources. These may be listed as follows: (1) Eastern Kentucky, including the Knobs, (2) Central Kentucky, or the Bluegrass Section, (3) The Mississippian Plateau, or central, southern and western Kentucky. (4) The Western Coal Fields. (5) The Jackson Purchase. While in some of the previous reports on the Kentucky Geological Survey the individual counties of these respective districts have been treated in alphabetic order, it has seemed wise in this report owing to the comparatively small number of counties in which molding sands accur to treat as a unit in alphabetic order such counties as contain molding sands. Therefore, in the description of the molding sands of Kentucky this order will be followed.

The above mentioned sections were visited and studied to ascertain the number of banks, beds, or pits of molding sand in active operation within the state, the approximate supply of such deposits, the uses to which the various sands were put in the different foundries and in constructional work in some instances, to secure samples for standard mechanical analyses and to glean

some knowledge as to the economic importance of the widely distributed molding sands of Kentucky. Some attention was also given to the means and cost of transportation from given sand pits to the nearest railroad station and to the possibility of shipping the better grades of sand beyond the borders of the state.

The above investigations have led to the conclusion that there are approximately 10,000,000 tons of molding sand in Kentucky. This tonnage must include certain decomposing or slightly cohering sandstones that may be used as core sands or in constructional work.

There are several different ways in which the molding sands of Kentucky may be classified as : (A) According to texture: (1) Fine grained. (2) Medium grained. (3) Coarse grained. (4) Fine gravel containing no pebbles more than one-half inch in diameter. (B) According to the nature of bonding material: (1) Clayey matter or hydrous aluminum silicates. (2) Iron oxides. (3) Clayey matter and iron oxides. (4) Pressure as equivalent to a very slight amount of bonding material. (5) Absence of all bonding substances. (C) According to the use for which each sand is best adapted: (1) Heavy machinery. (2) Light machinery. (3) Aluminum and brass foundary work. (4) Core work. (5) Floor sand. (6) Facing sand. (D) According to strength: (1) Strong sand. (2) Weak sand. Molding sand is called strong when it contains enoungh clayey matter so that when dried it becomes hard and will not crumble. A weak sand is one containing only a small percentage of clayey matter and thus having but little strength at the usual temperature and hardness.

Field Work

The field work for this report was done during June, July, August, and September, 1924, and July, August, and September, 1925. Incidentally, it may be noted that the author of this report prior to the summer of 1924 had done geologic work in every one of the 120 counties of Kentucky and therefore counties known definitely not to contain molding sands were not revisited during 1924 and 1925, thereby saving the state both time and expense.

As noted in the preface, 36 samples of molding sand were collected. 24 samples were sent to Professor H. Ries, Cornell University, for analysis and 12 samples were sent to Professor N. M. Fenneman, University of Cincinnati. The results of these analyses will be given under the caption of Mechanical Analyses in a subsequent chapter in this report.

Methods of Sampling

Samples of molding sand were obtained from two different sources. (1) Samples collected from cars nearly filled or full and ready for shipment. (2) Samples from active banks, beds or pits.

In the case of samples secured from cars on sidings 50 pounds or more of the sand was gleaned from the entire length of the car and the entire breadth of the car along several lines so as to get as nearly as possible a representative sample of the entire consignment. This sample was then uniformily mixed.

The samples from banks, beds, and pits were taken over a large portion of the working face so as to give an average of the grade of sand produced from that particular deposit. Where the upper portion of the deposit was a heavy molding sand and the lower portion a core sand, or an aluminum and brass sand, each type was sampled separately.

Laboratory Work

None of the samples collected have been tested by the author himself. As already intimated 24 of them have been mechanically analysed by Professor H. Ries and his assistants in the foundry laboratory at Cornell University, and 12 of them by Professor N. M. Fenneman and his assistants in the foundry laboratory of the University of Cincinnati. The equipment of these laboratories is understood to be as specified in the Standard Test Procedures recommended by the American Foundrymen's Association and the results as elsewhere given in this report are therefore comparable with the results of other organizations or laboratories using standardized tests.

CHAPTER II.

CHARACTERISTICS OF MOLDING SAND

Molding sand is sand used for the purpose of forming a mold, and possessing the quality of resisting the pressure of molten metal as well as the heat. It must be porous or open when compressed in order to allow the free escape of gases generated by the heat of the metal. The term also includes those sands which are used on the floors of plants manufacturing brick to keep the green brick from sticking to the floor, and also on the inside of the mold in which the bricks are pressed.

The sands generally used for green and dry sand molding are a natural mixture of sharp sand and a certain percentage of clay that acts as a binder. Sharp or angular grains are preferable to flattened or rounded grains for they can be perfectly rammed around the pattern and make a porous and pemeable mold.

Facing sand is sand placed next to the pattern in making a mold in order that the sand will yield or part from the casting freely and leave a smooth surface.

Core sands include all sands that can be used as a core in making castings for machinery. Core sand is any sharp sea sand or nearly pure silica.

Composition of Molding Sand

Molding sands are practically a mixture of silica and clay with varying amounts of iron oxides, lime and magnesia compounds, organic matter and water. The essential qualities are porosity, plasticity, and refractoriness. The amount of silica present in a given sand determines its refractoriness. The shape and size of the grains and the quality of the clay bond also effect the heat resisting qualities. The less iron, manganese, lime and magnesium compounds the sand contains the better it is for molding purposes. If a sand contains much alkali it will fuse into the surface of the casting and give off gases which will produce holes in the finished product. There are very few molding sands that cannot be improved by the addition of

40 to 50 per cent of silica sand, as glass sand. 60 per cent silica sand, and 40 per cent fine sand may be used. Molding sands vary from nearly pure silica up to 40 per cent of clay or analagous material. They are strong when they contain a considerable amount of clayey matter. They are mild or lean when they consist of almost pure silica. Such sands demand an artificial or added bond, to impart plasticity and cohesion.

The percentage of clay permissable in a molding sand according to some authors is as follows viz.:

Light brass 30 per cent.
Heavy brass and light iron 25 per cent.
Medium iron 20 per cent.
Heavy iron 15 per cent.
Steel 3 per cent.

Ferric oxide is not harmful up to certain amounts and for many purposes very desirable. Lime, for use in steel casting should not exceed 0.5 per cent, for iron work 1.5 per cent, for brass foundry work 2.5 per cent. Manesium compounds should be entirely absent, or at least they should not exceed 0.5 per cent, for they act as a flux. Alkalies should be present in less than 1 per cent for they also are fluxing material.

Requisites

Molding sands for general foundry work should meet the following requirements:

1. They should consist chiefly of silica.
2. The sand grains should be as uniform as possible in size.
3. Each grain should be covered with a thin film of clay, or limonite, or other bonding material.
4. The refractoriness should be high so as to resist fusion. It must withstand the action of the molten metal with which it comes in contact.
5. The permeability should be high so as to permit the escape of gases. A sand may have a low permeability and a high porosity, and a sand with high permeability is not necessarily highly porous. Permeability is measured by the rate at which gas or water will pass thru the sand, but porosity is measured by the amount of water required to fill the voids.
6. The porosity of the sand should be high. The term is applied to the relative volume of pores or interstices between the solid particles.

7. The plasticity should be high so that they may be easily fashioned into desired forms.

The porosity of sand depends upon the following factors, viz.:

1. The shape of the sand grains.
2. The size of the sand grains themselves.
3. The amount of bonding material present.
4. The amount of moisture present.

The plasticity of molding sand depends upon the following factors, viz.:

1. The proportion of clay or other bonding material present.
2. The bonding power of the clay or other bonding material.
3. The size of the grains of sand.
4. The various shapes of the grains of sand.
5. The chemical composition of the sand.

It is not definitely known what shape of grains produce a mass with the maximum strength, or what shape will produce the requisite porosity and permeability in the mold, or what smoothness in the grain is the most highly desirable. It is however, known that sharp angular grains are stronger than round ones, and that rounded grains give a more permeable mass.

Color

The color of molding sand varies from almost pure white thru yellow to red, but the color is not generally considered of great importance. The depth of color is indicative of the iron content but not an accurate test.

Green Sand

In green sand molding the raw sand in its undried or green state is used. The term green sand in no way refers to the color of the sand or the mineral known as green sand, a hydrous potassium-aluminum silicate. The term undried sand would not be misleading. Green sand is employed for malleable iron molding, chilled iron, steel, small brass and bronze castings.

Dry Sand

In dry sand molding, the mold is made of damp sand which has been previously dried. The moisture therefore is not the moisture of sand in its natural state but from water added in making the mold. Dry sand molds are used for large castings of all kinds, many small castings and cores.

In loam molding no pattern is used. The sand is shaped by hand into the desired form. The mold can therefore be used only once. It is not used where many duplicate castings are required. The sand for this type of molding may be either a natural or artificial mixture of sand and clay in proper proportions. Its disadvantages are: (1) The amount of labor involved in making the casting bed. (2) The adhesion of sand to the casting.

Requisites for molding loams are as follows: (1) Plasticity. (2) Small shrinkage. (3) Cheapness. (4) Sufficient refractoriness.

Requisites For Facing Sand

Facing sand which is placed next to the metal must possess the following requirements, viz.:

1. The sand must generate in use as little gas as possible.
2. Its permeability must be sufficiently high to permit the escape of gases and air.
3. It must be sufficiently refractory to withstand the high temperatures of the molten metal.
4. It must be sufficiently strong when molded to withstand the wash and pressure of the incoming metal.
5. It must give a smooth, fine appearance to the surface of the metal.
6. It must allow the castings to leave the mold cleanly.
7. It must be economical in cost.

Substitutes

The substitutes for facing and sand are: (1) Diatomaceous earth. (2) Brick dust. (3) Silica flour.

The non-sandy facings are: (1) China clay. (2) Fire clay. (3) Brick dust. (4) Broken crucibles. (5) Talc. (6) Graphite. (7) Coal. (8) Coke. (9) Charcoal. (10) Cinders. (11) Sawdust. (12) Composition, generally known in foundry work as compo. (13) Dung.

Requisites For Core Sands

In addition to the general requirements for molding sands the core sands must possess the greatest possible strength and sufficient venting power.

Requisites For Parting Sands

1. Fine texture.
2. Uniformly rounded grains.
3. Freedom from clayey matter or other bonding materials.
4. Freedom from fluxes, such as soluble salts and lime compounds.

Composition of Core Sands

Core sands are nearly pure silica SiO_2. They should be free from clayey matter, oxides of iron and the carbonates of calcium and magnesium because they make the core crumble. Organic matter aids in binding but burns out, making the core liable to crumble.

The value of core sands is determined by the shape of the individual sand grains, their fineness and their chemical composition. Sands high in silica and low in aluminum are required. Within certain limits the coarser the sand the greater will be the strength of the core. For general work sand is selected having a degree of fineness between 55 and 75. Sand coarser than 75 makes a weak core.

Mixes

1. Heavy sand for large work requires 6 parts of new sand, 3 parts of road sand, 6 parts of floor sand, and sufficient coal dust to show up brightly when rubbed on the handle of a shovel.

2. Medium sand requires 4 parts of new sand, 6 parts of floor sand, and 2 parts of coal dust.

3. Fine sand for light casting requires 4 parts of new sand, 10 parts of floor sand, and 1 part of coal dust.

Large cores require lake or sea shore sands. Medium sized cores require 2 parts of sharp sand and 1 part of molding sand. Small cores require 1 part of sharp sand and 3 parts of molding sand.

Core Binders

Core binders are: (1) Dry compounds. (2) Paste. (3) Oil. (4) Binders capable of being dissolved in water.

Dry compounds are made from rosin, dextrine, coke dust, pitch, and sometimes a little sawdust. Paste binders are usually flour which burns out readily. Oil binders are linseed, fish, and mineral oils. The soluable binders are molasses and glue.

Origin

In origin the molding sands of Kentucky fall into 4 groups. (1) Fluviatile. This includes most of the banks, beds and pits and this type is the large contributor to the molding sand wealth of the state. (2) River sands. These are pumped largely from the Ohio River, but also from the Kentucky, Cumberland and Tennessee Rivers, washed and screened to the desired sizes. Such sand is not quite as satisfactory on account of the clayey matter is may contain. (3) Glacial sand. Such deposits occur two miles southwest of Ashland and also directly south of Covington. (4) Decomposing or loosely cohering sandstones of Pennsylvanian Age. Such sands occur in Caldwell, Carter, Grayson and Hardin Counties.

Proofs of Fluviatile Origin

The molding sand deposits of the Covington-Newport district and of the Louisville district have always been considered to be of eolian origin. This theory of origin cannot hold true. It was the author's good fortune in the summer of 1924 to find in the molding sand deposits on the right of Taylor Avenue in the Bellevue district, 8 feet below the surface in a section some 15 feet in length and 1 foot in thickness, many fossils varying in size from a fraction of an inch up to nearly 2 inches in diameter with the striations or plications of the original calcium carbonate perfectly preserved. These shells have been sent to the National Museum for identification.

In other deposits in the Covington-Newport district shells were found in the field work this summer. The range in altitude is between 700 and 750 feet.

In the C. N. Ridgway sand deposit on Crane Run about 15 miles southwest of Louisville the author of this report during the field work this summer found 7 different species of gastropods. They range in size from a fraction of an inch up to nearly 2 inches in diameter and were perfectly preserved. Some of them were very delicate pipe stem-like forms up to one-half inch in length. These species occur scattered here and there the entire length of a 300-foot working face with a height of 40 to 50 feet. Some of them were near the top and some of them were burried under 40 feet of sand. Such shell bearing sand cannot possibly be eolian. These specimens have also been sent to the National Museum for identification.

Furthermore, practically all the sand deposits above the Ohio River flood plain in the Louisville district carry shells of gastropods, but they are more numerous at Crane Run and Medora than elsewhere. Some were found in the small sand deposits within the city limits of Louisville. The range in altitude of the shell deposits is from 575 feet to 750 feet.

Another argument against the molding sands of the Covington-Newport district being eolian is that in Kenton County on the east side of the Amsterdam Pike and just outside of the city limits of Covington the heavy molding sand carries pebbles from a fraction of an inch up to 5 inches in length, 3 inches in width and 3 inches in thickness. The pebbles are quartzites, jaspers, cherts, granites and diorites. Their surfaces were fairly fresh as if they belonged to the Illinoian ice movement.

Economics

The average price of molding sand per short ton in 1923 was \$1.21. It is lower than the price per ton for glass sand and reported to be higher than the price for core sand. The total tonnage of molding sands produced in the United States in 1923 was 5,559,644. This was valued at \$6,730,417. Of this amount Kentucky produced 43,653 tons valued at \$51,021.

The price for core sands is not listed separately in the available reports of the United States Geological Survey nor is the annual output given either in tonnage or value for core sands.

CHAPTER III.

Tests of Molding Sands

In the analysis of the different samples of sand collected and sent to Prof. H. Ries, Cornell University, Ithaca, New York, Chairman of the American Foundrymen's Association, the following tests were made: (1) Fineness. (2) Clay substances. (3) Dye absorption. (4) Per cent of water. (5) Bonding strength. (6) Permeability. The result of these tests will appear as a separate brief chapter later in this report.

The same set of tests were made in the foundry laboratory of the University of Cincinnati by Prof. N. M. Fenneman and his assistants and these results will appear in the same chapter with those made at Ithaca, New York. The second set of samples, however, in no way duplicate the first set, for the samples were taken from banks, beds and pits that had not been previously sampled. There is therefore no duplication of work, whatever.

The various foundry laboratories scattered thruout the country are working in cooperation with the American Foundrymen's Association and the National Research Council in an effort to standardize the tests made upon various molding sands, to ascertain the chief characteristics of various sands and to prevent losses in the various foundries.

Fineness Test

This test gives the amount of colloidal material in the sand and the percentage of various grain sizes down to 270 mesh. In making the fineness test, Bureau of Standards brass sieves are used. Those used are Nos. 6, 12, 20, 40, 70, 100, 140, 200, and 270. The largest sieve is placed on top and a receptacle is placed at the bottom to catch the grains, which pass a 270 mesh. These seives are placed in a Ro-Top machine or its equivalent and shaken. The weight of sand remaining on each sieve is determined. The larger the sample selected, the greater will be the length of time required for the operation. The American Foundrymen's Association uses a 50 gram sample, the laboratory

at Ithaca a 100 gram sample, the laboratory of the United States Radiator Corporation a 300 gram sample.

If the sand contains clayey matter as a bond the clayey matter must be removed before the sieve testing is made. This is done by shaking for a given period of time a sample of sand of a given weight with a given volume of water to which a given volume of sodium hydroxide has been added. The sand is washed with water until the supernatant water is perfectly clear, then filtered, dried and screened.

Clayey Matter

The amount of clay substances a molding sand contains is determined by the amount of clay removed by the last test, described above. This amount ranges in the samples submitted to the laboratory at Ithaca from no clay substances in the sandstone from 8 miles north of Olive Hill in Carter County to 42.50 per cent in a sample of heavy molding sand from 1½ miles southeast of Newport in Campbell County. The clay substances in all the samples collected will be found in the chapter on results of analyses.

Dye Absorption

The purpose of this test is to show the nature of the clayey matter present. The differences in the absorption capacities of different molding sands is due exclusively to the quantity of colloidal matter present in the sand. The heavily bonded sands are therefore high in colloidal content and dye absorption test and sands with little bonding material present are low in colloidal content and dye absorption test. The colloidal material present consists mostly of the hydrated aluminum silicates and the hydrated oxides of iron and silica. It is to these colloidal complexes that the plasticity of the molding sand is due. In making the test a crystal violet dye is used. For a description of the test the reader is referred to pages 58-61 of the Report of the American Foundrymen's Association on Tentatively Adopted Methods of Tests published June 1, 1924.

Percentage of Water

Two different methods of determining the percentage of water in sand may be used. One requires a considerable period of time and the other only a few moments.

In the first case the percentage of moisture in sand is determined by drying a sample of definite weight in an oven at a temperature of between 105 and 110 degrees Centigrade until a standard weight of the sand is reached. The loss in weight will equal the percentage of moisture.

The shorter method is volumetric. The determination is made by placing 860 grams of sand in a flask which has been previously filled with water. The displaced water is conducted into a glass tube the height of whose water calumn gives the moisture reading. A definite amount of water is displaced by each percentage of water in the sand. A thoroughly dry sand can displace only a small amount of water while a wet sand will displace a large amount of water.

Cohesiveness or Bonding Strength

This test gives the bonding strength of the sand and the temper at which the bond is the greatest. The cohesiveness of sand or bonding strength is determined by a compression test and is expressed in the table of results of analyses in Chapter VI in pounds per square inch. The sand to be tested is uniformly rammed into a cylindrical form 1⅛ inches in diameter and from 1¾ to 2 inches in length. The strength of this cylindrical specimen is determined by oil pressure. The specimen breaks suddenly when the load reaches the ultimate strength of the sand.

The bonding strength test may also be made by molding moist sand in to a bar 18 inches in length, 2 inches in width, and 1 inch in thickness. As the end of the bar is pulled by machinery beyond the end of the plate on which it rests, pieces of the bar break off. These are caught and weighed. The greater the bonding power in a molding sand the longer will be the pieces broken from the bar.

Base Permeability

The permeability test gives the vent developed by a sand and the temper at which the vent is the greatest. The base permeability of a sand is determined after the clayey matter has been removed. The sand grains are rammed into the permeability specimen retainer and held in place by means of No. 70 screens on each end. Air is forced through the sample and

the manometer reading will indicate the openness of the sand grain structure.

For a full description of the permeability test the reader is referred to the paper by Prof. H. Ries, Chairman of the Sub-Committee on Standard Tests of the American Foundrymen's Association entitled "The Testing of Molding Sands."

Other tests are sometimes used for molding sands that do not appear in the foundry laboratory at Ithaca, New York, upon the samples submitted to that laboratory from Kentucky. One of them is the heat test which requires a much longer period of time than the above tests so briefly described.

CHEMICAL ANALYSIS

An ultimate chemical analysis of molding sands is sometimes made to determine the percentage present of water that may be eliminated at a temperature between 105 and 110° C, of aluminum, iron and titanium as oxides present. The percentage of silica, alkaline earths and alkalies is also wanted. The value of the chemical analysis lies largely in determining the amount of fluxing material in a given sand. The value of the chemical analysis should not be overlooked in the case of new or untried sands.

Alfred B. Searle in his work on Sands and Crushed Rocks, Vol. II, recommends the following tests for molding sands.

1. Chemical analysis, including the determination of the moisture present, which is important.
2. Minerological examination, especially as regards the percentage of quartz, clay and fluxing constituents present.
3. A sizing or grading test to show the proportion of coarse, medium, fine sand, silt, clayey matter, etc.
4. A microscopical examination to determine the shape and other properties of the grains and also the nature of the impurities present in a given sand.
5. Plasticity or bond absorption test.
6. A refractoriness test.
7. A porosity test.
8. A permeability test.
9. Strength test, (a) tensile, (b) crushing, (c) transverse.

CHAPTER IV.

DESCRIPTION OF DEPOSITS

The molding sand deposits of Kentucky as described in this chapter have been visited by the author of this report and in many instances samples were collected for analysis as elsewhere noted. It is not to be inferred that every possible molding sand deposit in Kentucky has been found. A pit active on year may become quiescent the next year. Therefore pits marked inactive signifies that they were not in operation in either 1924 or 1925.

The various counties producing molding sand are taken up in the descriptions of deposits in alphabetic order. The continuous serial numbers in the margin, 1 to 103 are given to ascertain the total number of molding sand deposits in the state. Numbers from 1001 to 1024 refer to the numbers given these samples by Professor Ries in his analytical work.

BOYD COUNTY

Sample No. 1 *Ries, No. 1002*

Molding sands occur in the southwest corner of the City Park, Ashland, Kentucky, in an inexhaustible supply. The deposit is controlled by the City Park Commission and the output used directly as a molding sand. The length of the working face is 120 feet and the height is 20 feet. This deposit extends back thru the park for a long distance. While a considerable amount of sand has been removed this summer from this sand bed, it is understood that the City Park commission has refused the right of further excavations. This sand contains some clayey matter and hydrated iron oxides as bonding material. It is fluviatile in origin and Recent in age.

Sample No. 2 *Ries, No. 1003*

This sample of molding sand came from the property of the Norton Iron Works, Ashland, Kentucky. The deposit is located by Lexington Avenue and 24th Street. This pit has a possible length of 250 feet and the height of the working face is 40 feet. This sand carries less iron oxide as a bond than the sand in the

City Park. It is regarded as a core sand and the supply is ample. In origin it is fluviatile and Recent in age.

Sample No. 3

Molding sands occur on the river side of Lexington Avenue in Ashland, Kentucky, between 25th and 26th Streets. The

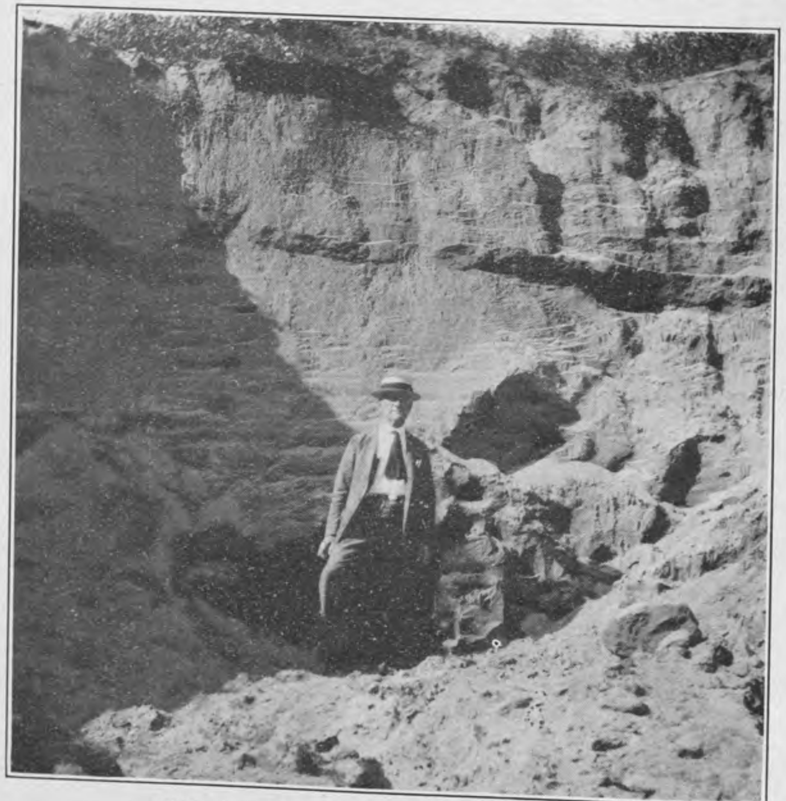

FIG. 1. CITY PARK SANDS, ASHLAND
Molding sand pit in City Park, Ashland, Boyd County, Ky. This pit is controlled by the City Park Commission.

breadth of the opening is about 200 feet and the height of the working face is 40 feet. This sand carries less bonding material than the deposit in the City Park. From excavations for foundations and from the records of wells driven for water it was ascertained that molding sand of one grade or another extends from Lexington Avenue to Greenup Avenue, a distance

of 6 blocks, and from 20th Street to 28th Street, a distance of 8 blocks. All these sands are fluviatile and Recent.

Sample No. 4 *Ries, No. 1006*

The molding sand on the farm of Thomas Smith is situated 2 miles southwest of Ashland, Kentucky, and one-half mile east of The Midland Trail, but still within the city limits of Ashland. The length of the working face may be easily made 200 feet and

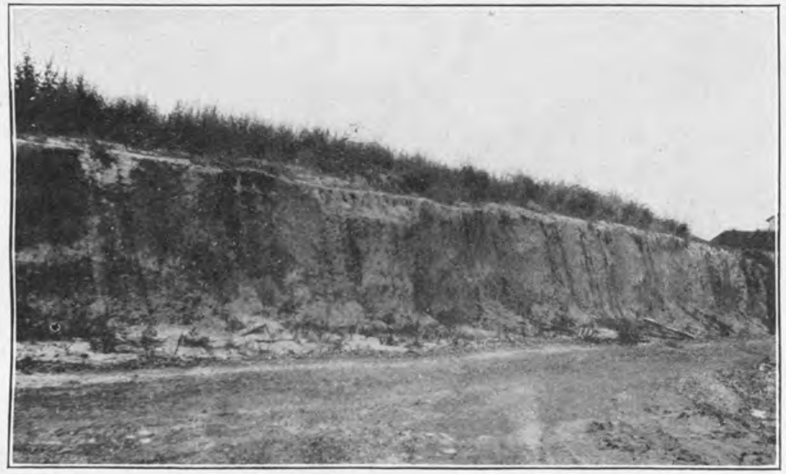

FIG. 2. GOOD BOYD COUNTY SANDS
Upper bed of the Tom Smith molding sand deposit, Ashland, Boyd County, Ky. An equal depth of core sand constitutes the floor in the foreground.

the height 20 feet. The upper 10 feet is a heavy molding sand with both clayey matter and iron oxides as bonding material. This sand is not only used locally, but it is also shipped to the American Car and Foundry Company, Huntington, West Virginia. The sand is hauled 2 miles in motor trucks for shipment. It appears to be of glacial origin, associated with the ponding of waters. The lower 10 feet of this deposit carries less clayey matter and is used as common molding sand, core sand, and in concrete work. The lowest portion of this deposit is of Pennsylvanian age. The supply is large.

Sample No. 5

One and one-half miles from the Thomas Smith farm on property owned by John P. Gartin there is a 12-foot bed of molding sand. The upper 6 feet of this bed is a good molding sand. The lower 6 feet is a sharp sand perhaps best used as a core sand and in the manufacture of concrete. The supply is ample. The upper 6 feet appears to be of glacial origin associated with the ponding of waters. The lowest portion is of Pennsylvanian age. This sand is hauled by motor truck about 3 miles to Ashland.

Sample No. 6

The Ashland Housing Company owns a sand deposit near the church in Westwood just outside the city limits of Ashland. This bank shows 4 feet of molding sand and 4 feet of core sand stained by iron oxides. Transportation to Ashland is by motor truck. The supply is somewhat limited on account of the numerous dwellings constructed upon this particular deposit. As this bed is on the high altitudes to the west of Ashland, the upper portion may be of glacial origin but the lower portion is of Pennsylvanian age.

Sample No. 7

On the Midland Trail near the city limits of Ashland, on the line of contact of property owned by S. A. Douglass with that owned by Charles Slim, there is a bed of decomposing sandstone of Pennsylvanian age which has been used as a core sand to a limited extent and to a greater extent for plastering and concrete work. It is a sharp sand rich in iron content. The clayey bonding material is very slight. This sandstone unquestionably extends back into the higher altitudes and a large working face could easily be secured.

Sample No. 8.

At Summit, on property owned by the Ashland Brick and Tile Company there is a small pit of molding sand that is used by the above named company as a floor sand. It is possible that excavations in the pasture between the road and the mill would reveal the deposit to cover a considerable area, but the depth would probably not exceed 5 feet. Shipment could be made by the Chesapeake and Ohio Railroad for haulage to this railroad would be only a few rods. The deposit is regarded as fluviatile in origin and Recent in age.

Sample No. 9

Two miles north of Ashland on the Ohio River side of the Ashland-Greenup Pike in Boyd County, but just south of the Greenup County line, there is a deposit of very fine sand of uniform grain. It contains a little clay binder. A working face 75 feet in length with height of 7 feet could easily be secured. This sand has been worked as a brass molding sand with good satisfaction. It is also well suited for aluminum work. Since this deposit is within 10 rods of the Chesapeake and Ohio Railroad, transportation to the railroad for shipment would be reduced to a minimum in cost. The ownership of this sand deposit is unknown. Its origin is fluviatile and its age Recent.

Sample No. 10 *Inactive*

Between the village of Princess and the tunnel of the Chesapeake and Ohio Railroad, only about 100 feet from the railroad, and on the northwestern side of the Midland Trial, there occurs a large bed of decomposing sandstone of Pennsylvanian age. A working face more than 100 feet in length and 30 feet in height could easily be secured. The bonding material or cement binding the sand grains together is so limited in amount that the sandstone reduced easily to a fine medium grade of sand. It is white or yellowish white in color and of uniform texture. It should make a fairly satisfactory high silica core sand and is a good glass sand.

Bullitt County

Sample No. 11

This sand bank is on the farm of Julia Bickle about 40 rods east of the railway station at Katharyn, Bullitt County, Kentucky. More than 1,000 tons of molding sand have been shipped from this bank. The sand was hauled by teams 40 rods down grade to the railway station at Katharyn for shipment. A working face 100 feet in length and 30 feet in height could easily be secured. About 6 feet from the top of the sand bank there are a few sand-lime concretions but these soon disappear. They

could be easily screened out, and the sand in the bed in which the concretions occur could be used as molding sand. The supply of sand here is ample. Its origin is fluviatile and its age Recent.

Sample No. 12 *Fenneman, No. 6*

This sand pit is also on the Julia Bickle farm and about 4 rods from the house. It is also about 10 rods east of the rail-

FIG. 3. GOOD SAND DEPOSIT, PRINCETON
Section of loosely cohering sandstone, Princeton, Caldwell County, Ky. This sandstone makes a white to yellowish white core sand.

way station at Katharyn. A 50-foot working face 20 feet in height could be secured. A considerable amount of sand has been shipped from this pit yet a large tonnage still remains for the sand extends back under the house and across to No. 11 bank. The sand is a very fine grained and of uniform texture. It is so nearly white that it is locally called "Sugar Sand." This pit was active in 1923 but inactive in 1925. The sand is fluviatile in origin and Recent in age.

CALDWELL COUNTY

Sample No. 19 *Ries, No. 1001*

On property owned by W. F. Holeman, 601 East Market Street, Princeton, Kentucky, there occurs a bed of consolidated sand or sandstone. This quarry is situated about 1 mile north-

east of the Courthouse at Princeton and about three-fourths of a mile from the Illinois Central Railroad. The quarry is about 150 feet in length and about 40 feet in height. The sand in the upper 20 feet is somewhat iron stained on the surface but when the sand grain is broken open it is often pure white in color or in places only slightly iron stained. The sandstone is so pliable that large blocks break down directly into sand by a single blow of the hammer. Or even when a given block of sand-

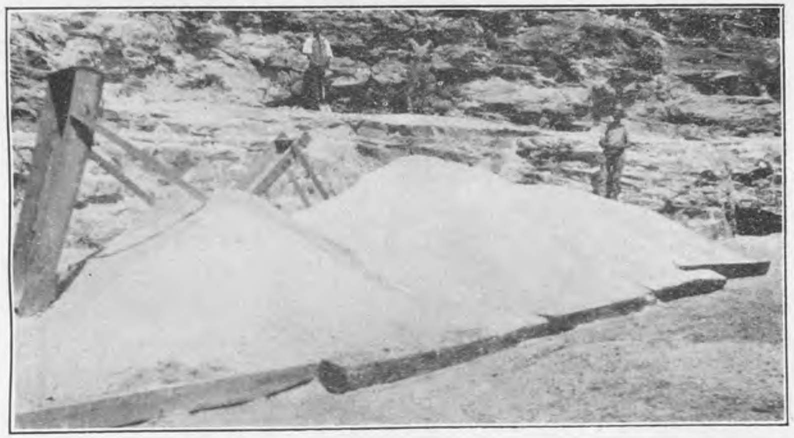

FIG. 4. A CALDWELL COUNTY SAND DEPOSIT
W. F. Holeman sandstone quarry, Princeton, Caldwell County, Ky. The sandstone is crushed and screened for core sand.

stone is dropped on the quarry floor it reduces directly to sand grains that are round or subangular in form and of even grade. Only 0.50 per cent remains on sieve No. 270. A chemical analysis of this sand shows only 0.32 per cent ferric oxide and 0.62 alumina. It is therefore a high silica sand well suited for core work. The supply is very large and the overburden is shallow. The age of the sandstone is Mississippian.

Sample No. 14 *Inactive*

A second quarry also owned by W. F. Holeman is situated about one-fourth mile toward Princeton from the quarry described as No. 35. The product is approximately the same grade with perhaps a little more of the sand iron stained which does no harm for its use as core sand but detracts somewhat from its

value as a glass sand. These two quarries are connected under a mantle of thin soil. The supply is practically inexhaustible for there are about 40 acres of this sandstone. The age of the sandstone is Mississippian.

Calloway County

Sample No. 15 *Inactive*

This sand deposit is located three miles east of Murray on the Newburg road. A 100-foot working face with a height of 20 feet could be secured. The sand is nearly pure white in color, of uniform grain, and of fine to medium texture. The bed was operated for several years for plaster, concrete and core sand work but it is now inactive. Distance from railroad may be the cause. The sand bed is fluviatile in origin and of Cretaceous age.

Sample No. 16 *Inactive*

About one mile west of New Concord there occurs an appreciable amount of white sand of uniform grain and fine to medium texture. It has been used for plaster and concrete sand and could be used as a core sand. Clayey matter and iron oxides are absent. The sand is fluviatile in origin and of Cretaceous age.

Sample No. 17 *Inactive*

Eight miles due east of Murray, between the New Pine Bluff Road and the Old Pine Bluff Road there occurs an inexhaustible supply of core sand. This sand bed extends back for a long distance under the bluff. The sand is white in color, fine to medium in texture and of uniform grain. This sand was used as a mortar sand and a small core sand for many years. Distance required for haulage is the reason the deposit is inactive. The sand is of fluviatile origin and of Cretaceous age.

Sample No. 18 *Inactive*

This sand deposit occurs at Edge Hill, twelve miles southwest of Murray. This sand is white in color, fine to medium in texture, and has been used for plaster, mortar, concrete and could be used for fine casting. It is fluviatile in origin and of Cretaceous age.

Campbell County

Sample No. 19 *Fenneman, No. 1*

This sand deposit occurs on the lowland between Newport and Bellevue, Campbell County, Kentucky. The property is controlled by the Newport Sand Bank Company of 5th and Mammouth Streets, Newport, Kentucky. A working face several hundred feet in length is possible with a vertical face 50 feet in height. The material is not uniform in size for a part would be classified as gravel, a part as coarse sand and a part as core sand. The material would have to be screened to uniform size for molding purposes. The sand is beautifully cross bedded. There is an overburden of a few feet of soil that should be removed. Many thousands of tons have been removed and many thousands of tons still remain. This sand and gravel is fluviatile in origin and of Recent age.

Fig. 5. SAND DEPOSITS NEAR NEWPORT
Sand and gravel deposit, Newport, Campbell County, Ky. The cut shows the bedding planes in the sand and the height of the working face.

Sample No. 20 *Fenneman, No. 2*

This deposit occurs just beyond the Chesapeake and Ohio Railroad bridge over Taylor Street, Bellevue, Kentucky. A working face 100 feet in length and 20 feet in height could easily be secured. The upper portion of the bed could be used

for molding sand. The central portion for aluminum and brass work for it is very fine and of uniform texture. The lower portion contains a considerable amount of clay. This material was being hauled away this summer for some fill.

Sample No. 21 *Ries, No. 1012*

This sand bank is situated on the right hand side of Taylor Avenue, Bellevue, Kentucky. The sand bank is some 100 feet

FIG. 6. CAMPBELL COUNTY SAND DEPOSITS
Molding sand bank, right hand side of Taylor Ave., Bellevue, Campbell County, Ky. This cut shows the bank in which gastropods were found in 1924.

across it, but by working around the knoll a bank several hundred feet in length could be secured with a working face of from 5 to 10 feet in height of good molding sand. This property is operated by the Newport Sand Bank Company. That this deposit is fluviatile in origin is proven by a bed containing many gastoropods ranging in size from a fraction of an inch up to nearly 2 inches in diameter and perfectly preserved. Several different species were found in a bed 8 to 10 feet below the top of the bank in a section some 15 feet in length and about one foot in thickness. The deposit is Recent in age. This sand is marketed as No. 5 B.

Sample No. 22

This deposit represents a new opening on the back side of the same hill that carries No. 19. A working face could be secured around the entire hill with a height of face from 5 to 10 feet. The supply is ample. It is fluviatile in origin and of Recent age.

FIG. 7. LOADING SAND, BELLEVUE
Molding sand bank, Taylor Street, Bellevue, Campbell Co., Ky. This cut shows the method of loading sand.

Sample No. 23 *Inactive*

On the higher altitudes to the left of Taylor Ave., Bellevue, Kentucky, molding sands have been obtained but no deposits are now active. The supply is not exhausted. The sands are fluviatile in origin and of Recent age.

Sample No. 24 *Ries, No. 1008*

On the higher altitudes just outside the city limits of Bellevue and to the southeast there occurs several sand banks owned and operated by the Newport Sand Bank Company. Sample

Ries, No. 1008 was taken from the upper $2\frac{1}{2}$ feet. The working face is perhaps 100 feet in length, and about 5 feet in height The upper $2\frac{1}{2}$ feet is sold as No. 4 W. It contains more clayey matter and iron oxides than the lower $2\frac{1}{2}$ feet. Its origin is fluviatile and its age is Recent.

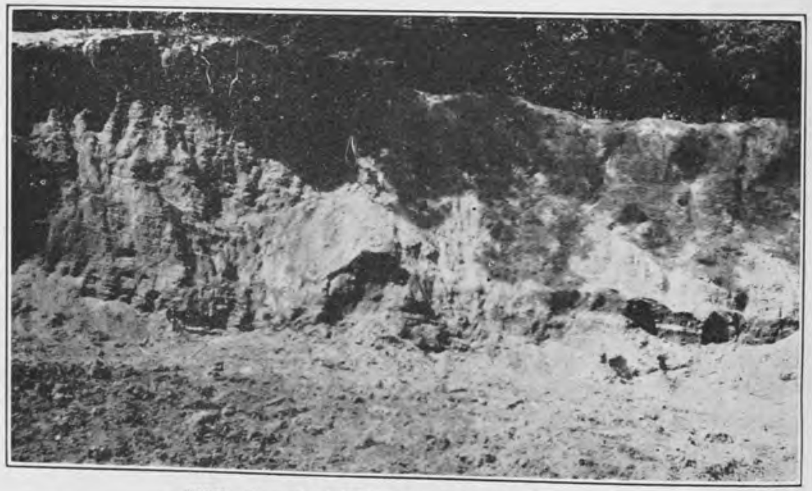

FIG. 8. MOLDING SAND, NEWPORT
Heavy molding sand bank. Newport Sand Co., Newport, Campbell County, Ky. This bank is in the Bellevue district.

Sample No. 25 *Ries, No. 1009*

This sample was taken from the lower $2\frac{1}{2}$ feet of the deposit listed as No. 22. It is a little finer sand than No. 22 and is sold as No. 5 W. The supply is not large. The sand is fluviatile in origin and Recent in age.

Sample No. 26 *Ries, No. 1010*

This deposit occurs about 500 feet to the left of No. 22. A circuitous working face of 100 feet linear distance with a height of from 2 to 4 feet shows that a large amount of sand has been removed. The supply is nearly exhausted. This sand is sold as No. F. core sand. It is fluviatile in origin and Recent in age.

Sample No. 27 *Inactive*

This sand deposit is situated about one mile south of the Court House in Newport on what is known as Jones Hill. The

pit has been inactive for several years. The sand contains a few pebbles that may have been the cause of the pit becoming idle. In the immediate neighborhood there is a very large supply of sand that also contains a few pebbles. These sands are fluviatile in origin and of Recent age.

FIG. 9. OLD SAND PIT, BELLEVUE
Heavy molding sand deposit, Bellevue, Campbell Co., Ky. This cut shows a bank that is nearly exhausted.

Sample No. 28 *Ries, No. 1014*

This sand deposit is situated about one mile south of the port in the Cold Springs district. It is also controlled by the Newport Sand Bank Company. There is a 150 foot linear working face varying from 12 to 15 feet in height. A linear face of 200 feet could easily be secured. There is about 2 feet of overburden to remove. This sand is red in color and of uniform grade. It is hauled $1\frac{1}{4}$ miles to Brent for shipment and is sold as No. 2 Red. It is fluviatile in origin and of Recent age.

Sample No. 29 *Ries, No. 1018*

The Kennedy sand beds are situated about 25 miles southeast of Newport at Mentor, Kentucky. The deposit is about $\frac{1}{2}$ mile southeast of Mentor Station on the Chesapeake and Ohio Railroad. The sand is hauled about 25 rods to a spur on the Chesapeake and Ohio Railroad for shipment. The deposit is owned by F. O. Kennedy and operated by Warren J. Kennedy and George W. Watson. The working face is about 400 feet in

length and 40 feet in height. On the top there is about 2 feet of heavy loam sand then 15 feet of aluminum and brass sand, beneath which there is at least 25 feet of molding sand. Beneath the molding sand there is sand of unknown thickness for plaster and concrete work. The supply of sand seems practically inexhaustible. Five different grades of sand are shipped from this deposit.

1. Open core sand and concrete sand at bottom.
2. Open brass sand finer in grain than No. 1 and with more bonding material.
3. Gray iron and malleable iron castings. This sand has a heavier bond than No. 2. The sample No. 1018 in chapter on Analyses came from this section from a car load lot ready for shipment to the Detroit Piston Ring Company, Plymouth, Michigan.
4. Alumnium and light castings as for Delco light plants.
5. Heavy loam and machinery sand. This is on top and completes the section.

The Kennedy sand has six recognized characteristics.

1. High silica content.
2. Low alumina content.
3. Low iron content.
4. Low lime content.
5. Scales of muscovite rare.
6. Sand-lime concretions very rare.

The above sand is fluviatile in origin and of Recent age.

Carroll County

Sample No. 30

More than 50,000 yards of sand and gravel have been pumped from the Ohio River at Carrollton by the Carrollton Sand and Gravel Company of Corrollton, Carroll County, Kentucky. The river sand is sharp, clean and would make a core sand when properly screened and sized. The supply of this river sand is inexhaustible. Screening and drying adds somewhat to the expense of production.

Sample No. 31 Ries, Nos. 1019, 1020, 1021

The James Gayle sand and gravel pit is situated one mile southwest of Carrollton. It is owned and operated by James Gayle of Carrollton. More than 12,000 tons of sand and gravel have been shipped from this deposit and the supply is inexhaustible, for a bed 500 feet in length of working face and 50 feet in height can easily be secured.

A vertical section of this pit as opened gives the following, viz., reading from top down:

1. Two feet of soil containing clay.
2. Five to six feet of heavy loam or machinery sand.
3. Five to six feet of red molding sand with narrow or thin layers more clayey.
4. Five to six feet of gray sand containing a few pebbles.
5. Fifteen feet of good gravel.
6. Five-foot bed of white sand.
7. Five-foot bed of fine gravel, but the bottom of the bed has never been reached. It is known in the neighborhood that some of these deposits exceed 100 feet in thickness.

Sample No. 1021 was taken from the red molding sand bed five to six feet in thickness.

The above sands are fluviatile in origin and Recent in age.

Carter County

Sample No. 32 Ries, No. 1007

This deposit is located about 8 miles north of Olive Hill, Carter County, Kentucky, on the county road extending up Henderson Branch over Trough Camp Creek. It is also about one mile south of Lewis County line. The formation is a sandstone of Pennsylvanian age. The length of the formation exceeds 1,000 feet. The breadth is unknown and the known thickness is 30 feet. Haulage would be 8 miles to Olive Hill. A part of the formation is without overburden and a part has just enough soil to support timber growth. The composition is nearly pure silica. There are a very few minute scales of mica. There is no lime in it, no lumpy impurities, and no clayey matter. It readily splits into thin slabs, and is easily crushed. It has been used in the manufacture of high silica bricks, and should make a good core sand. The property is owned by the Olive Hill Refractories Company, Olive Hill, Kentucky.

Sample No. 33

The General Refractories Company of Olive Hill operates a quarry of sandstone that is situated about one-half mile west of their factory and just above the Chesapeake and Ohio Railroad. The lower 15 feet of this sandstone is white or faintly yellowish white in color, free from grains of feldspar and practically free from scales of mica. The grains are angular to subangular and easily loosened from each other when struck with a hammer. In fact, the stone is so friable that it can be easily reduced to a high silica sand well suited for core sand or the manufacture of glass.

The upper 20 feet of this quarry is iron stained largely due to ground waters carrying iron compounds in the overlying soil down among the loosely cohering grains.

The crused sands from this quarry are now used as an excellent molding sand. It is spread over the floor of the factories of the General Refractories Company and the Harbison-Walker Brick Company to keep the green brick from sticking to the floor, and on the inside of the mold in which the brick are pressed to prevent the brick from adhering to the molds. Incidentally this sand is used for mortar, plaster, cement and concrete. The above sandstone is of Pennsylvanian age.

Sample No. 34

The Camp Glass Company of Huntington, West Virginia, owns and operates a quarry at Tygart. The quarry is situated on the south side of the Chesapeake and Ohio Railroad and only a few hundred feet from the track. A spur extends to the crusher and storage bins. The elevation of the quarry is about 100 feet above the railroad track.

This sandstone varies in thickness from 30 to 40 feet. The upper 15 feet is more or less iron stained. The lower 15 to 20 feet is white or yellowish white in color of medium grain, angular to subangular in form and both a good core sand and glass sand. The American Car and Foundry Company of Huntington, West Virginia, uses this sand. The formation is of Pennsylvanian age.

Sample No. 35

This quarry is situated only a few hundred feet west of the one listed and described as No. 22. It is owned and operated by the same company, crushed in the same mill, shipped from the same point and has the same characteristics.

Sample No. 36 *Inactive*

This sandstone deposit is situated about 2 miles due west of Tygart and about one-fourth mile from the Soldiers Fork of Tygart Creek. It is owned by Dr. G. R. Logan of Enterprise. The sandstone outcrop is more than 1,000 feet in length and 30 feet in thickness. It is white to yellowish white in color, of uniform grain and without any lime or clay content. It is a loosly cohering sandstone of Pennsylvanian age and an excellent core sand.

Sample No. 37

The Interstate Molding Sand Company of Lawton, or Tygart, Carter County, Kentucky, owns 6 acres of molding sand 20 feet in thickness of deposit. The upper 10 feet contains clayey matter as bonding material. The lower 10 feet is a coarser and sharper sand and contains more iron oxides than the upper bed. The sand is shipped to Ashland to the American Rolling Mill Company and to the Ashland Clay and Metals Products Company; to the Kenova Mine Car Company, Kenova, West Virginia; to the Kanawha Manufacturing Company, Charleston, West Virginia; to the Southern Wheel Company, St. Louis, Missouri; and to the Simpson Brothers, Portsmouth, Ohio.

Fulton County

Sample No. 38 *Inactive*

In the southern part of Fulton County near the Tennessee border there occur beds of sand containing a large amount of clayey matter and iron oxides as bonding material. The Read and Little Foundry in Fulton rather than use these possible molding sands around Fulton use some sand from Paducah and purchase the remainder of their sand from producers in Illinois and Missouri. The molding sand used by the foundries around Hickman is all obtained from the Missouri side of the Mississippi River.

Molding sand occurs 6 miles southwest of Hickman and about one-fourth mile from the Illinois Central Railroad. The deposit which is owned by John W. Smith, of Hickman, represents a rather coarse and sharp sand that is heavily iron stained. The bed is about 10 feet in thickness and extends over a large area. The sand is fluviatile in origin and of Cretaceous age.

Graves County

Sample No. 39 *Inactive*

Around Mayfield in Graves County, Kentucky, there occur vast beds of gravel containing an appreciable amount of sharp sand. It is understood that these gravels have been screened to obtain molding sand for the Mayfield Foundry at Mayfield, but this foundry has purchased the most of its molding sand from Paducah. A sharp core sand can be screened from the Purchase gravels which are of fluviatile origin and Cretaceous age.

Sample No. 40 *Inactive*

In borings made by the City Water and Light Plant in and around Mayfield a good core sand was encountered at a depth of 200 feet. This sand extends to a depth of 290 feet, therefore making a total thickness of 90 feet. It is a clean, sharp, white sand of uniform grade as seen in samples pumped up from the sand bed. The bed is known to cover a large area in Mayfield and its environs, and may be catalogued as a core sand reserve.

Grayson County

Sample No. 41 *Inactive*

In the ravine just east of Leitchfield, one-half mile from the Court House, and on the eastern boundary line of the town of Leitchfield, the Big Clifty sands have been obtained and used for plaster, mortar, cement and concrete. They are reddish brown in color, of medium grain and would make a core sand. They are of Mississippian age, and 40 feet in thickness.

Sample No. 42 *Inactive*

On the farm of Jesse C. Lee, one mile northeast of the Court House at Leitchfield and some 40 rods from the Illinois Central Railroad small quarries have been opened in the Big Clifty sandstone to secure sand by crushing the sandstone for

building purposes. The sand varies from white to yellowish white in color. The grains are medium in size, free from scales of mica and would make a core sand. The supply is ample. The age is Mississippian.

Sample No. 43 *Inactive*

On the farm of James Morris about three-fourths of a mile northwest of the Court House and one-half mile from the Illinois Central Railroad there occurs an old quarry in this same Mississippian sandstone. This stone is very friable and easily reduced to a yellowish white core sand of uniform grade. Many of the Big Clifty sandstones around Leitchfield are so friable that they reduce to sand grains as soon as struck with a hammer. Some of them are white and others are yellowish white in color. They all appear of uniform texture.

Greenup County

Sample No. 44

A small deposit of molding sand that is used for machinery work occurs at Schieler Point, Greenup County, Kentucky. This narrow strip of sand is some 50 feet in length, 30 feet in width, and varies from 2 to 6 feet in thickness. A few hundred tons of sand only are available. This sand is regarded as too coarse for aluminum and brass foundry work. To the south, the sand grades out into gravel, and to the north is the Schieler Cemetery which cuts off the otherwise available supply. Between the remaining small bed and the Schieler Cemetery the sand has been removed for foundry work.

Sample No. 45

In the north end of Russell at the mouth of Bear Run there is a sand bed 150 feet in length and at least 50 feet in thickness that has been extensively worked as a pit. The north end of the sand bed is cut off by dwellings. The sand itself is of even grain, remarkably pure and is regarded as one of the best core sands of the state. The pit has been extensively worked and a large amount of sand still remains. The sand is fluviatile in origin and of Recent age.

Sample No. 46 *Ries, No. 1004*

Between the Ashland-Greenup Pike and the Chesapeake and Ohio Railroad, about 5 miles south of Greenup and east of Raceland, there occurs a sand bed one-half mile in length and one-fourth mile in width that has been worked to a limited extent. The sand contains a few quartz pebbles that can be easily screened out. The deposit is owned by the Chesapeake and Ohio Railroad. It is fluviatile in origin and of Recent age.

FIG. 10. MOLDING SANDS IN GREENUP
This cut shows a large aluminum and brass foundry sand reserve.

Sample No. 47 *Ries, No. 1005. Inactive*

At the north end of the Raceland property there is a very extensive sand bed that was operated prior to the construction of the Raceland track. This sand is of fine uniform grain and apparently well suited for aluminum and brass foundry work. The supply is very large. The sand was sampled so that all of its characteristics might be known and the sand utilized in case the Raceland track should be closed. The sand is fluviatile in origin and of Recent age.

Hardin County

Sample No. 48

The Kentucky Silica Company with office at 14th and Gallagher Streets, Louisville, Kentucky owns and operates a large molding sand deposit at Tip Top, Hardin County, Kentucky. F. C. Dickson is superintendent of the plant at Tip Top.

The plant is located about one-half mile northwest of the Tip Top station on the Illinois Central Railroad and about 7 miles east of the Ohio River. The sand deposit covers approximately 40 acres and is about 50 feet in thickness. The sands consists of a sandstone that is so soft and so poorly cemented that it crumbles to sand when touched. In color it ranges from white thru a yellowish white to yellow. The upper 25 feet has been stained somewhat by iron oxides leached from the overburden of soil. The lower beds some 25 feet in thickness are pure white save where surface waters have come in contact with them. The grains are very fine, clear, quartz sand. In a few instances there are small lenses of from 2 to 6 inches in thickness of a yellow and white clay interstratified with the sand. The extreme lower portion of the bed carries some small lenses of magnesite, $MgCO_3$, and on the floor of the pit a few samples of periclasite, MgO, were obtained. A few chert pebbles appear on the floor of the pit.

Five different grades of sand are produced by the Kentucky Silica Company.

1. **No. 1. Molding Sand. This is a yellowish sand which is sold to the foundries as a molding sand, to brick factories to cover the floor to keep the green brick from sticking and to line the inside of the molds in which the brick are pressed.**
2. **No. 4. Heavy Molding Sand. This sand is shipped to steel mills for heavy castings. The Louisville and Nashville Railroad is a large producer. Sand from this pit is shipped to Louisville, Kentucky; Cincinnati, Ohio; Richmond, Indiana; Nashville, Tennessee; Columbus, Georgia; and Albany, Alabama.**
3. **No. 1. Glass Sand. This sand is pure white or a faintly yellowish white, used in the manufacture of glass. It is also a core sand.**
4. **No. 2. Glass Sand. This sand is yellowish white from iron stain. It is also a core sand.**
5. **No. 3. Run of Mine Sand. This mixture contains the sand from the white beds at the bottom of the pit, the overlying iron stained beds and about 2 feet of the overburden of soil.**

This pit has been active for more than 25 years and over 250,000 tons of sand have been mined and shipped from this single pit. The present output is 10,000 tons per annum.

Sample No. 49

The Kentucky Silica Company operates a heavy molding sand pit on the east side of the Illinois Central Railroad. The present opening is 100 feet in length but could easily be made 200 feet, 15 feet in height of working face and with some 2 feet of overburden. The supply is ample.

Sample No. 50

The Kentucky Silica Company operates a sand bank on the west side of the Dixie Highway and only a few rods from it. This sand contains an oil charged sand lens varying from 4 to 6 inches in thickness. The supply is ample.

Sample No. 53 *Inactive*

About one-half mile from Tip Top on the farm of W. F. Scheible there is an old sand pit from which some 25 carloads of sand have been shipped. The sand is identical with those of the Kentucky Silica Company. The supply is not exhausted.

A part of these sands at Tip Top are so free from bonding material that they may be shoveled directly into trucks for haulage for only a few rods to the Illinois Central Railroad. A part of them are so feebly bonded together that 80 to 100 pounds pressure of water breaks them up into individual sand grains. In reality they represent a disintegrating sandstone known as the Big Clifty formation which is Mississippian in age.

Sample No. 54

E. F. Schwindler of Louisville, Kentucky, operates a sand bank on the west side of the Illinois Central Railroad about one-tenth mile north of East View. The quarry face is about 200 feet in length and approximately 40 feet in height. There is an overburden of about 3 feet of soil. The upper 2 feet of sand is red to reddish yellow in color from the infiltration of iron oxides from the overburden of soil. The remainder of the sand is white or faintly yellowish white high silica sand. This sand is so close to the railroad that the cars are loaded on a passing track. The sand contains no lenses of magnesite, no flint nodules, but it does carry a few small nodules of pyrite, FeS_2. These can be removed by proper screening. The sand is shipped as foundry sand to the Louisville Fire Brick Co. and as glass sand to the N. D. Dupaw Glass Company, New Albany, Indiana. The deposit extends over some 25 to 30 acres and is therefore ample.

Sample No. 55 *Inactive*

On the east side of the Illinois Central Railroad and almost opposite No. 54 there occurs some 25 acres of sand practically identical with the sand described as No. 54. This deposit was extensively worked at one time but after the large storage plant was burned it was never rebuilt and the property was abandoned.

Sample No. 56 *Ries, No. 1022*

The Hermann Sand Company of Louisville operates a sand deposit that is located a few rods to the north of the Illinois Central Station at East View and on the east side of the tracks. The sandstone carries about 10 feet of molding sand. The deposit carries at the top about 3 feet of loam, then 6 feet of red molding sand and a yellowish white to white molding sand. This sand is a high silica sand derived from a sandstone that carries no clayey matter, no appreciable amount of iron oxides, no calcareous content, but does carry a few iron concretions.

In working this outcrop, quarry methods are utilized to break off the blocks of sandstone, but the sand grains are so loosely cohering that when a block is struck with a hammer, the stone breaks down into sand grains. Blocks break down in the same way on falling to the quarry floor. This sand is shoveled into wheelbarrows and loaded into a car standing on a siding.

Sample No. 57 *Inactive*

On the James M. Daugherty property about one mile northwest of East View, and on both sides of the Illinois Central Railroad, their occurs a large area of decomposing sandstone that closely resembles the sands at East View. This sand is not quite as good a molding sand for it carries a few more grains of pyrite.

Sample No. 58 *Inactive*

A considerable amount of this same type of sand occurs on either side of the Illinois Central Railroad just south of East View.

Sample No. 59 *Inactive*

One mile south of East View on either side of the Illinois Central Railroad, this same decomposing sandstone or loosely cohering sandstone appears in a bed at least 25 feet in thickness and may be more. It covers several acres. The sand grains are very white. These widely distributed occurrences prove an inexhaustible supply of molding sand especially for core work and floor work in brick factories in Hardin County. The sands of the East View district are all of the same age.

Henderson County

Sample No. 60

Molding sand occurs in large tonnage on the farm of William Elliott opposite Nicholson's Mills and on Sand Hill Road. The sand is of uniform medium grain with a little iron oxide and clayey matter as bonding materials. This deposit is also just outside the city limits of Henderson. It forms the ridge within the city limits between Green Street and Main Street. Some of these deposits have been used for over 40 years as building sands, paving sands, and more recently as a filler for asphalt in the city paving work. The most of the sand is iron stained. A part of the sand is sufficiently fine grained and of sufficiently uniform size to be used as molding sand by the aluminum and brass foundries. The sands are fluviatile in origin and of Recent age.

Sample No. 61

A large tonnage of gravel is pumped from the Ohio River just above Henderson and screened to various sizes. The sand screened out of this river gravel is a sharp angular, medium to coarse grained quartz sand that could be used in core work and must therefore be catalogued as molding sand possibility.

Jefferson County

Sample No. 62 *Fenneman, Nos. 11 and 12*

The Partman Sand and Gravel Company of 4130 West Chestnut Street, Louisville, Kentucky, owns and operates a sand and gravel pit on the west side of the Dixie Highway at Grote Park. The deposit is within 500 feet of the Illinois Central Railroad. The available sand area covers 14 acres. The overburden is about 2 feet in thickness. Beneath the soil there is 6 to 8 feet of heavy molding sand. This is underlain by 6 to 8 feet of fine aluminum and brass foundry sand. This in turn is underlain by 4 feet of sharp core sand, gravel then follows to a depth of 106 feet. Sample, Fenneman, No. 11 is from the heavy molding sand. Sample, Fenneman, No 12 is from the sharp core sand. The intervening aluminum and brass foundry sand was not sampled for analysis. The sand and gravel represent a river deposit of Recent age.

Sample No. 63

The Louisville Sand and Gravel Company operates a sand and gravel bed just east of 7th St., south of the Southern Railroad, and directly behind the property of the Gulf Refining Company. Many thousands of tons of sand have been removed from this pit. The upper portion is molding sand, the central portion core sand, the lower portion down to bed rock is gravel. The sand and gravel represent a river deposit of Recent age.

Sample No. 64

The J. C. Spoo sand bank is on the east side of Southern Parkway in South Louisville. There is here some 2 feet of heavy molding sand and 2 feet of core sand with but very little if any bonding material. The bank is 300 feet in length and about 300 feet in breadth. The supply is not large. It is opposite 4434 Southern Parkway. It is fluviatile in origin and of Recent age.

Sample No. 65

At 35th Street and Parker Street, Charles Berger has operated for several years a sand pit and gravel pit. The deposit covers 7 acres. The screened sand is core sand. It represents a river deposit of Recent age.

Sample No. 66

Charles L. Breehl operates a sand pit between 4th and 7th Streets. The supply is not large.

Sample No. 67 *Inactive*

On 18th Street just west of Maplewood, there are 2 inactive sand pits. It is not known to the author who owns the pits. The supply is not exhausted.

Sample No. 68

The Humpick Brothers with office at 524 E. Marrett Street operate sand pits located between Preston Street and Hancock Street. The sand is said to be continous between these two streets.

Sample No. 69 *Inactive*

On the east side of Taylor Boulevard at Edge Hill near Jacobs Park, there is quite a large knoll of good molding sand. This deposit has never been opened. It is fluviatile in origin and of Recent age.

Sample No. 70

Charles L. Breehl operates a sand bank on the east side of Ashland Avenue near Cliff Avenue. The molding sand has a depth of from 8 to 10 feet. A 100-foot linear working face can be secured. The sand is of uniform grain. It is also fossiliferous.

Sample No. 71

Charles L. Breehl operates also a sand bank on the west side of Ashland Avenue near Cliff Avenue. This section ranges from 4 to 8 feet in thickness and is fossiliferous. A few perfectly preserved shells of gastropods were found in each of these deposits on Ashland Avenue. These deposits are fluviatile in origin and of Recent age.

Sample No. 72

At Fort Hills on Preston Street there is a sand bank of the same character as that described as Nos. 70 and 71. The ownership is not known to the author.

Sample No. 73

Sand occurs in Louisville as a continuous product from 3rd Street to 13th Street. In many places the sand deposit has been operated as a pit on a small scale. These places are too numerous to list separately. A vertical section of this area gives:

1. Top soil, 2 feet.
2. Molding sand, 5 to 6 feet, clay loam.

3. Aluminum and brass foundry sand, 6 to 8 feet. It is largely used for castings and plate work.
4. Core sand, 10 feet. This is a sharp quartz sand used for core work, building and concrete.
5. Water laid gravel, 80 feet, from which some sharp core sand can be screened.

FIG. 11. JEFFESSON COUNTY SAND DEPOSITS
A section of the W. C. Moore molding sand bank, Medora, Jefferson Co., Ky. This deposit extends back through the corn field.

Sample No. 74

About 50 rods east or southeast from Stiles Station on the Henderson Railroad, there is a small deposit of molding sand from which some sand has been removed. It is not regarded as important.

Sample No. 75 *Fenneman, No. 7*

The W. C. White sand bank is located a few rods east of the railway station at Medora. The bed is some 500 feet in length, of equal breadth, and 10 feet in thickness. The overburden is light. The upper 4 feet has a greater bonding power than the lower 6 feet. The lower sand is fine grained and of uniform texture. Several thousand tons of sand have been shipped from this property. This sand is fluviatile in origin and of Recent age. It is fossiliferous.

Sample No. 76 *Fenneman, No. 8*

The T. B. Miller sand bank at Medora is located on the east slope of Miller Hill and is operated by Paul Miller. The pit

can have a linear working face of several hundred feet and a maximum height of 50 feet. The outer edges of the deposit would not reach this height of working face. At the bottom of the deposit there are a few sand-lime concretions. The sand is uniform in size and from this property thousands of tons have been shipped. Many gastropods were found in this bank. Some of them were 20 feet below the surface, more than 1 inch in diameter, and perfectly preserved. These extremely fragile forms, now buried beneath 20 to 40 feet of molding sand would prove these deposits fluviatile in origin and of Recent age. They cannot possibly be eolian.

Sample No. 77

This deposit is located a few rods to the east of No. 76 and also operated by Paul Miller. It is practically a continuation of No. 76.

Sample No. 78

The H. P. Pendleton sand deposit is also located at Medora and only a few rods from sample No. 75. It represents the same general type of sands as Nos. 75 and 76. It is on the right-hand side of the road, extending eastward from Medora.

Sample No. 79 *Fenneman, No. 9*

The C. N. Ridgeway sand bank is situated at Crane Run some 15 miles south of Louisville and about 30 rods from the Henderson Railroad. The working face is approximately 300 feet in length and the height is 40 feet. If carried back a little further a 50-foot vertical face would be secured. The sand is of uniform texture, and of medium grain. A very few sand-lime concretions occur in the lowest part of the deposit, but these are easily avoided. The supply of sand is very large. Seven different species of gastropods were found this summer in this deposit. Some of them were under 20 to 30 feet of sand. Some were an inch or more in diameter. Some were pipestem like forms one-half inch in length. Some were very small and yet perfectly preserved. These forms scattered through the entire length of the deposit and the entire height of the deposit, with their delicate forms and perfect preservation prove unquestionably that the molding sand deposits of the Louisville district are not wind blown or loess deposits, but fluviatile in origin and Recent in age.

Sample No. 80

The Frank Moore sand bank is located on Crane Run about 50 rods east of the Ridgeway deposits described as No. 79. It represents a small deposit for the working face is not more than 50 feet in length and 5 feet in height. The upper 2 feet has

FIG. 12. SAND DEPOSITS ON CRANE RUN
Section of C. N. Ridgeway molding sand bank, Crane Run, Jefferson County, Ky. This deposit contains several species of gastropods.

more bonding material than the lower 3 feet. The upper portion is a good molding sand. The lower portion is a medium grained core sand that is not regarded as quite fine enough for aluminum and brass foundry work. No sand-lime concretions were found in the Moore bank. This deposit is fluviatile in origin and Recent in age.

Sample No. 81 *Fenneman, No. 10*

The W. H. Thompson sand bank is situated about 12 miles south of Louisville and 1 mile north of Valley Station. It is also on the east side of the Dixie Highway. There is about 2 feet of overburden that should be removed. The present opening is semi-circular. A straight working face 500 feet in length could easily be secured. The height of the working face could be made 40 feet. The supply of sand is very large. The grade is uniform. A very few sand-lime concretions were found on the floor of the opening.

These can all be avoided. A few perfectly preserved specimens of gastropods are present in this sand deposit. The sand is fluviatile in origin and of Recent age. W. H. Cloud, of Louisville, has shipped much sand from this knollq The Sebolt Sand Company of Louisville has also been a shipper from this deposit.

FIG. 13. LARGE SAND DEPOSITS, JEFFERSON COUNTY
Section of the W. H. Thompson sand bank, Valley Station, Jefferson Co., Ky. A few gastropods appear as white spots on the working face.

Sample No. 82 *Inactive*

On the Mary Cunningham farm, which is the 2nd farm north of the W. H. Thompson property just described, there is a molding sand deposit that has never been opened. The sand is essentially the same as No. 81. This sand deposit could be opened and worked on a royalty basis. The supply is ample.

Sample No. 83 *Ries, No. 1024*

The largest molding sand deposit in the entire Louisville district is situated about one-fourth mile east of Pleasure Ridge Park. It is operated by W. H. Cloud, of Louisville. This bank has a working face of over 1000 feet in length, semi-circular in form and varying from 7 to 15 feet in height of working face. In the upper bed the material is all a heavy molding sand of uniform grade and with a strong binder. It does not appear that the sand has been removed to the bottom of the bed, especially

in the area now being worked. A very large tonnage of sand has been removed from this deposit. It is estimated that over 200,000 tons have been shipped in the last five years. At the lower level near the road there appears on the old eroded floor a few chert pebbles. These appear to be entirely absent in the upper levels.

FIG. 14. SAND DEPOSITS, PLEASURE RIDGE
W. H. Cloud molding sand bank, Pleasure Ridge, Jefferson Co., Ky. The upper bed is a heavy molding sand. The lower bed is a core sand. The unconformity is very marked.

Such chert pebbles may be beneath the present working floor. The sand is hauled by teams or trucks to Pleasure Ridge, a distance less than one-half mile, and loaded into cars for shipment. The sand is fluviatile in origin and of Recent age.

Sample No. 84

A few rods east of the large workings and at a lower altitude there is another large working face, but not as large as in No. 82. The upper six feet is a heavy molding sand like No. 82, but the lower 4 feet is a sharp core sand with little if any bonding material present. This sand is white to yellowish white in color and of uniform grade. The variation in the line of contact is at least 3 feet in altitude. The line of contact so sharply marked and so varied in altitude suggests an uncomformity that

required two different periods of deposition. Both types of molding sand are fluviatile in origin and Recent in age.

Kenton County

Sample No. 85 *Fenneman, No. 3*

The Schlosser Brothers of Covington own a molding sand bank that is situated on the east side of the Dixie Highway

FIG. 15. LOADING MOLDING SAND
Molding sand pit, Pleasure Ridge, Jefferson Co., Ky. This cut shows method of loading and haulage of sand.

about one mile south of Covington. The bank is operated by A. W. Moore of 905 Lewis Street, Covington, Kentucky. The sand is sold as Grade No. 4. However several different grades occur here. There is some 12 feet of Grade No. 2, which is used for light machinery work, also a No. 2 loam, and very fine sand well suited for aluminum and brass foundry work. Beneath the working floor there is clay and sharp sand of unknown thickness. A 100-foot linear working face could be secured with a 30-foot height. The supply is ample. The deposit is of fluviatile origin and of Recent age.

Sample No. 86 *Fenneman, No. 4*

This sand bank is also operated by A. W. Moore. It is located on the east side of Amsterdam Pike and just outside the

city limits of Covington. A 100-foot working face could be secured with height of 40 feet. The supply is ample. The sand is fluviatile in origin and of Recent age.

Sample No. 87 *Fenneman, No. 5*

This sand bank is also operated by A. W. Moore and is situated on the east side of Amsterdam Pike at a higher altitude

FIG. 16. KENTON COUNTY SANDS
Molding sand deposit, Covington, Kenton Co., Ky.

than No. 86. The working face here approximates 75 feet in length but could be made much greater and 30 feet in hight. It represents a heavy molding sand with a large amount of bonding material. It is interesting to note that in this bank there are boulders of granites, diorites, quartzites, jasper and chert. One chert boulder found this summer in the working fact was five inches in length. Such a molding sand could not possibly be windblown or eolian in origin but must be either fluviatile or glacial. The supply is ample.

Sample No. 88

In Devou Park in the City of Covington and just west of the shelter house in the park there is a very large and excellent molding sand deposit. The length of the working surface is 300 feet and the height is 65 feet. The sand is of fine texture, of uniform grain, and is an excellent aluminum and brass foundry sand. More than 100,000 tons of sand have been shipped from this deposit. It is fluviatile in origin and of Recent age.

FIG. 17. SAND AND GRAVEL AT LUDLOW
Sand and gravel bed Ludlow, Kenton County, Ky. In this section the gravel is in excess of the core sand.

Sample No. 89 *Inactive*

This molding sand is located in Devou Park about 40 rods due west of No. 88. It is much the same type of sand as No. 88. While a considerable amount of sand has been removed from this pit the supply has not been exhausted.

Sample No. 90 *Inactive*

This pit is located about 50 rods, southwest of No. 88 and also in Devou Park. The sand is like No. 89. The pit has not been exhausted. With this section now used for Park purposes, it is doubtful if any more sand will be removed from Nos. 89 and 90.

Sample No. 91

On the Light Estate on Light Hills now known as Park Hills a large molding sand bank has been operated by Rufus Light. There was a working face here at one time some 500 feet in length and more than 500,000 tons of molding sand have been removed. It is fine grained like that of Devou Park. The sand is fluviatile in origin and of Recent age.

FIG. 18. SAND CONVEYOR AT LUDLOW
Sand and gravel conveyor, Ludlow, Kenton Co., Ky. The material is being conveyed to the mill for screening.

Sample No. 92

Near the top of the hills in the region known as Park Hills there is a deposit of molding sand that is underlaid by a clay that is used by foundries and malleable iron works. The clay may be residual from the decomposition of the Eden shales but the sand appears to be fluviatile in origin and of Recent age.

Sample No. 93 *Ries, No. 16*

Charles Sperl of Covington owns from 25 to 30 acres of molding sand just south of Covington. In one of the three openings there is 10 feet of coarse sand that is very open and is a core sand. Two feet of high silica sand of fine texture, and 20 feet of

good molding sand. This bank carries a few sand-lime concretions which are easily removed. The sand is fluviatile in origin and of Recent age.

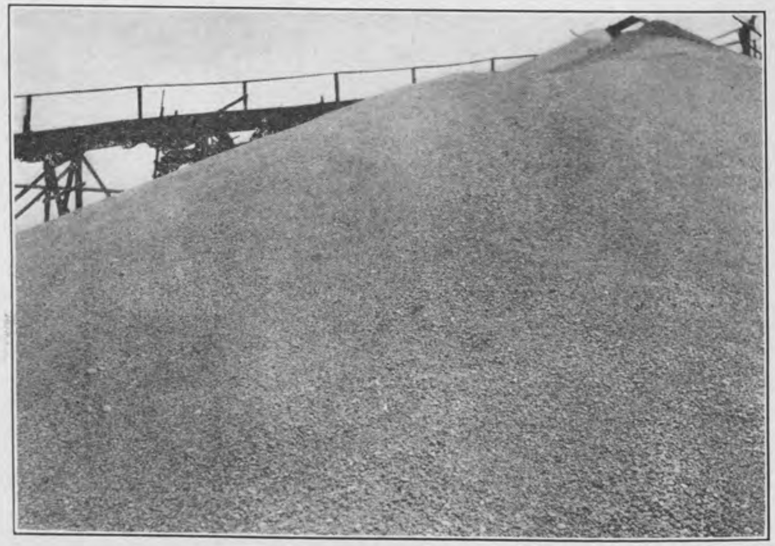

FIG. 19. SCREENED GRAVEL, LUDLOW
Gravel screened from sand, Ludlow, Kenton County, Ky.

Sample No. 94 *Inactive*

This deposit of molding sand is located on the Montague Road at its junction with Park Road. More than 1000 tons of sand have been shipped from this deposit but the supply is not exhausted.

Sample No. 95

The Joseph Eubanks molding sand beds are located at Crescent Springs. The supply is ample.

Sample No. 96 *Inactive*

One-half mile south of Latonia on what is known as the Parks property there is a small deposit of molding sand.

Sample No. 97

In Vissallie, 13 miles south of Covington on the K. C. Division of the Louisville and Nashville Railroad there is a good

molding sand deposit of ample supply. Two cars per month are shipped from this property. The sands are shipped as Grades No. 2, No. 3, No. 4.

FIG. 20. LOADING SAND AT GRAND RIVERS
Steam shovel loading gravel, Grand Rivers, Livingston County, Ky.

Livingston County

Sample No. 98

At the plant of the Memphis Stone and Gravel Company at Gravel Switch there is an unusually large and interesting gravel deposit. Its description does not belong in this brief work. The working face of this gravel bed is one-half mile in length and the height is 100 feet. The supply is practically inexhaustible. It has been suggested to the author several times during the last 2 years that by the removal of the pebbles by screening a most ex-

cellent molding sand would be secured. This product is so widely different from the well known molding sands of Kentucky that it would require very carefully conducted foundry experiments before the material could be safely marketed as a molding sand. The product is used in the construction of the state roads and as railroad ballast. It is shipped as far south as Alabama.

McCracken County

Sample No. 99

The Paducah Sand and Gravel Company of Paducah, McCracken County, Kentucky, pumps a coarse sand from the Ohio River near the foot of Campbell Street. This river sand is used largely for road work but could be screened a little finer and used as a core sand. The sand is now being shipped into Illinois and Tennessee.

Sample No. 100

The Paducah Sand and Gravel Company also pumps sand from the Ohio River just below the government lighthouse on Kincaid Island. This is a fine sand that is used for plastering and as a molding sand.

Sample No. 101

The Ohio River Sand and Gravel Company of Paducah, R. H. Noble, President, pumps a large tonnage of sand from the Tennessee River about three miles above Paducah. The sand is brought to Paducah by barges. Several different grades of material are shipped from this large plant.

1. Molding sand is screened 1/10 to 3/16 inch.
2. Concrete sand is screened 3/16 to ¼ inch.
3. Pea gravel for road surfacing is screened ¼ to ⅝ inch.
4. Concrete gravel is screened ⅝ to 2 inches.

Menifee County

Sample No. 102 *Inactive*

A molding sand deposit occurs in Menifee County between Rothschild and Frenchburg. It is located about 20 miles east by south 15 degrees from Mt. Sterling. The sand is a medium to coarse grained, rather sharp core sand. The long haulage to market would be very expensive. The supply is ample.

Montgomery County

Sample No. 103 *Inactive*

Sand Mountain is in Montgomery County near the junction of Slate Creek and Spruce Creek, about 10 miles southeast of Winchester. It would be about 5 miles to the nearest railroad. The sand is white to yellowish in color, medium to coarse grained and of large tonnage. The distance from the railroad of this deposit renders it inadvisable to work it at the present time. The supply is ample.

CHAPTER V.

ANALYSES

As stated earlier in this report, none of the analyses have been made by the author, for there is no foundry laboratory at Syracuse University. It may appear to some foundrymen, and others also, that all molding sand deposits of Kentucky should have been carefully sampled and analyzed. This seemed inadvisable to the author at the present time. However, as elsewhere noted 36 of the active deposits have been carefully sampled, analyzed and the results tabulated in this terse chapter. A study of these results will throw new light on the characteristics of the molding sands of Kentucky and afford a means of comparison between the molding sands of Kentucky and those of other states. One hundred and three deposits have been visited, of which 73 are active and 30 are inactive.

KENTUCKY

Bold face type figures indicate greatest bond strength and permeability.

Lab. No.	Locality	Grade if Used	Fineness Test												Dye Adsorption	Water Per Cent	Bond Strength	Permeability
			On 6	On 12	On 20	On 40	On 70	Ou 100	On 140	On 200	On 270	Through 270	Clay Substance	Total				
1001	Caldwell Co. Princeton	Friable Sandstone	......	......	.18	1.40	64.44	23.34	5.50	1.10	.50	.44	2.92	99.82	240	Dry	......	102.
1002	Boyd Co. Ashland	River Deposit	......	2.24	4.58	12.58	67.94	6.34	2.14	.70	.58	.64	2.36	100.10	224	3.3 5.9	....	**440.** 341.
1003	Boyd Co. Ashland	River Deposit	......	.58	.38	2.34	61.20	24.54	4.48	1.68	1.70	1.30	1.76	99.96	96	Dry	......	119.
1004	Greenup Co. Raceland	River Deposit	1.20	5.64	5.80	28.80	48.54	2.58	.54	.28	.34	.68	5.62	100.02	460	2.4 3.0 3.9 6.1	...... **135** 108 73	358. **492.** 417. 398.
1005	"		......	Tr.	.14	1.74	93.30	2.84	.30	.10	Tr.	.14	1.42	99.98	140	Dry	......	326.
1006	Boyd Co. 2 miles s. w. Ashland	Decomposed Sandstone	......	......	.44	3.40	25.28	18.18	17.24	5.84	3.04	4.30	21.96	99.68	1344	3.8 6.4 8.4 10.7 12.2 14.2	...... 271 284 294 **307** 244	16.7 36.0 42.0 **60.0** 49.0 11.8
1007	Carter Co. 8 miles n. Olive Hill	Sandstone	......	......	......	13.32	13.32	10.07	14.95	16.37	14.79	16.52	......	99.34	284	Dry	......	2.6
1008	Campbell Co. 1½ miles s. e. Newport	Molding	......	......	......	......	.24	.34	1.08	1.88	11.20	44.20	41.10	100.04	2496	6.9 8.5 10.1	281 **297** 279	6.0 **7.9** 7.7
1009	"		......	......	......	Tr.	.44	.30	.68	1.34	7.30	47.48	42.50	100.04	1656	6.0 8.3 10.1 11.4 13.2	...... **233** 223	4.2 4.4 5.8 **7.5** 5.3
1010	"	Core	......	......	......	Tr.	12.60	34.34	22.54	10.74	8.30	6.16	5.36	100.04	384	3.7 5.9 7.8	86 **99** 98	63. **85.** 80.
1011	"		......	......	......	Tr.	.98	3.90	4.44	6.68	17.90	45.54	20.26	99.70	1344	6.2 8.2 9.5	183 **190** 182	8.5 **10.0** 7.9
1012	"		......	......	Tr.	.14	5.44	12.54	11.80	11.80	18.70	26.68	12.16	99.26	780	6.2 7.8 9.8 11.7	142 143 146 **147**	13.8 **29.0** 21.0 19.5
1013	"		......	Tr.	.18	.54	6.80	15.74	12.90	12.74	18.50	26.28	6.00	99.68	384	4.2 5.7 7.7 9.9 10.6	111 118 126 **130** 125	24.2 **29.0** 23.4 20.0 19.5
1014	Campbell Co. 10 miles s. e. Newport		......	......	......	Tr.	6.54	46.78	13.44	3.00	2.04	3.04	25.26	100.10	2136	6.5 8.5 10.8 12.2	...... **371** 354	47. 58. **67.** 40.
1015	Kenton Co. Covington	General Foundry	......	......	.24	1.74	22.76	17.54	9.14	6.86	7.06	11.30	22.82	99.46	2176	6.7 8.6 10.8 12.0 12.9	261 **355** 336	14.3 22.7 36.0 **55.0** 40.0
1016	"	No. 3	......	......	Tr.	.08	.34	.78	6.14	13.20	28.96	36.78	13.76	100.04	804	5.9 7.9 9.9 11.7 14.5	143 151 152 156 **161**	10.0 **17.8** 11.0 11.0 7.0
1017	"	Heavy Machinery	......	Tr.	.84	6.04	37.90	13.40	4.44	1.68	1.80	3.54	30.72	100.36	2724	6.8 9.1 10.2 12.9	323 **375** 360	105. 142. **219.** 178.

KENTUCKY

Bold face type figures indicate greatest bond strength and permeability.

Lab. No.	Locality	Grade if Used	Fineness Test On 6	On 12	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Substance	Total	Dye Adsorption	Water Per Cent	Bond Strength	Permeability
1018	Campbell Co. Mentor	No. 3					.44	1.64	3.70	5.14	14.64	48.94	25.52	100.02	832	6.0 7.9 9.7	168 **171** 165	4.2 **6.0** 4.7
1019	Carroll Co. Carrollton	Core			Tr.	2.20	95.68	1.34	.24				1.00	100.46	96	Dry		358.
1020	"			2.58	4.70	9.40	71.68	7.40	1.44	.30	.28	.48	1.50	99.76	140	Dry		193.
1021	"	Molding		Tr.	.40	4.14	67.64	15.28	2.78	.88	.84	1.38	6.72	100.06	736	2.8 3.9 6.3	 **178** 125	205. **243.** 219.
1022	Hardin Co. East View	Sandstone			Tr.	.04	5.84	45.34	24.54	7.56	2.54	1.10	2.86	99.82	216	2.2 3.8 5.5	 **95** 90	75. **85.** 80.
1023	Jefferson Co.	Molding					1.04	12.90	14.88	7.64	7.00	28.44	17.70	99.60	704	5.8 7.9 8.7	167 **175** 168	6.7 **9.4** 8.2
1024	"						1.10	13.68	16.18	7.90	7.04	36.20	17.64	99.74	804	4.2 5.6 7.8 9.2 13.3	163 **171** 164 	7.2 7.7 8.8 9.7 **10.7**
66	Campbell Co.	Gen. Foundry and Molding			.04	2.26	30.95	24.34	9.00	4.26	2.44	10.31	16.40	100.00		4.5 6.2 7.5 11.0	116 136 121 	20.4 39.8 51.6
67	Kenton Co.	Foundry, Light Machinery			.04	.08	.48	3.46	11.08	16.62	12.20	34.94	21.10	100.00		4.5 5.8 7.7 9.0	163 193 201 200	3.8 5.3 6.7 7.4
68	"	Molding		.04	.02	.02	.14	.96	6.68	15.34	16.26	49.86	10.68	100.00		4.1 6.1 7.0 9.3	121 137 143 145	8.7 9.6 10.2 9.8
69	"	Molding Heavy Machinery	.28	.22	.54	1.46	14.94	24.85	17.10	8.16	3.94	8.35	20.16	100.00		3.4 6.0 8.1 9.0	258 329 325 	11.5 20.7 26.3 25.0
97	Jefferson Co.	Molding	2.24	.22	.22	.22	.38	.30	.54	1.20	1.94	65.46	27.28	100.00		4.3 5.7 7.7 9.0	124 154 174 168	2.7 3.2 3.8 3.1
98	Bullitt Co.	Foundry			.02	.12	2.58	3.78	4.94	5.88	6.37	58.28	18.05	100.00		3.8 5.8 7.0 8.9	130 165 156 150	4.8 5.7 6.2 6.3
99	Jefferson Co.	Core		.34	1.48	24.37	31.41	4.64	2.08	1.86	.80	1.36	1.66	100.00		3.7 5.4 7.6 8.9		
100	"	Molding		.02	.02	.06	1.46	13.62	21.55	14.33	6.82	17.15	24.96	100.00		4.0 5.2 7.9 9.5	246 275 333 291	8.6 12.3 17.0 19.1
101	"	Heavy Molding				.16	.32	.46	3.30	9.52	11.11	55.71	19.42	100.00		4.2 6.1 7.9 9.7	118 156 179 164	3.6 5.0 6.7 6.2
102	"	Molding			.02	.02	.22	.16	.20	.56	1.72	64.78	32.32	100.00		3.5 6.1 7.6 9.6	180 190 175 172	1.8 2.3 2.4 2.5
103	"	Molding	.44	.52	.62	.52	.30	.16	.20	.70	1.40	65.50	29.64	100.00		4.1 5.6 7.3 9.5	165 174 195 182	2.1 2.4 2.5 2.6
104	Campbell Co.	Core	2.32	1.82	6.16	58.36	26.36	1.36	.94	.64	.20	.48	1.36	100.00		4.0 6.0 7.0 9.0		

CHAPTER VI.

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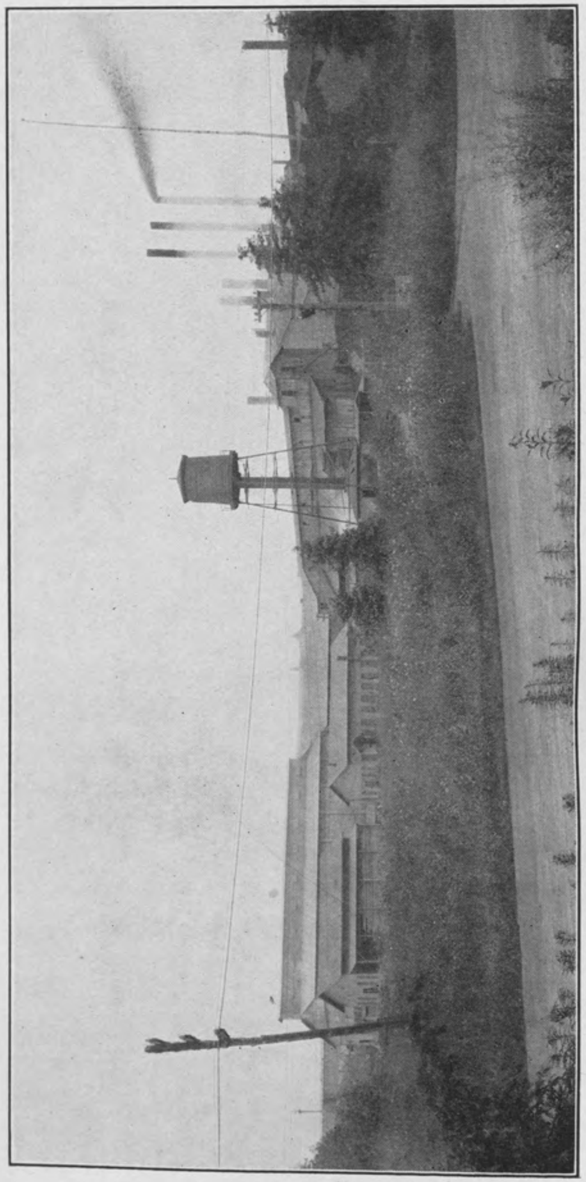
CEMENT MATERIALS OF KENTUCKY



CEMENT PLANT, KOSMOSDALE, KENTUCKY

PHOTOGRAPH BY W. R. JILLSON

CEMENT MATERIALS OF KENTUCKY

By
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Assistant Geologist

THE KENTUCKY GEOLOGICAL SURVEY
FRANKFORT, KY.
1927

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CEMENT MATERIALS OF KENTUCKY

By Charles Henry Richardson, Ph. D.

CHAPTER I.

INTRODUCTION

The specific investigation of the cement materials of Kentucky was undertaken not only to provide information of practical value to general libraries, boards of trade and chambers of commerce, but also to land owners and investors. Owners of magnesium free limestone deposits, sedimentary clay and shale deposits are especially desirous for this type of information. Investors in manufacturing industries have been particularly desirous of knowing where, within the Commonwealth of Kentucky, limestones and clays of suitable composition for the manufacture of cement can be found. Cement manufacturers in other states have questioned, where, in the expansion of their own industry, new cement plants can be established to the best advantage within the State.

To answer these questions, it is necessary not only to have the limestones and clays suitable for cement manufacture definitely located, but also to have available the chemical analysis of cement materials, the physical properties of the requisite clays, the available fuel supply for burning the products, transportation routes for handling the finished material, and proximity of markets for consuming the cement.

In the preparation of this brief work, each of the above factors have been taken into consideration. The report is not intended as a manual of cement manufacture, not as a treatise on cement testing, not as a report on cement utilization, but rather as a discussion of the possible cement materials of the State.

The report also has to deal with a series of definitions of the different kinds of cements and their characteristic properties, the raw materials that enter into the manufacture of the various types of non-hydraulic and hydraulic cements, the preparation and burning of the mix, the distribution of cement materials of whatever type within the State and a brief survey of the cement industry of the United States. The last is necessary in order to settle the question of supply and demand, for if the supply was in large excess over the demand, it would not warrant the construction of another cement plant in Kentucky.

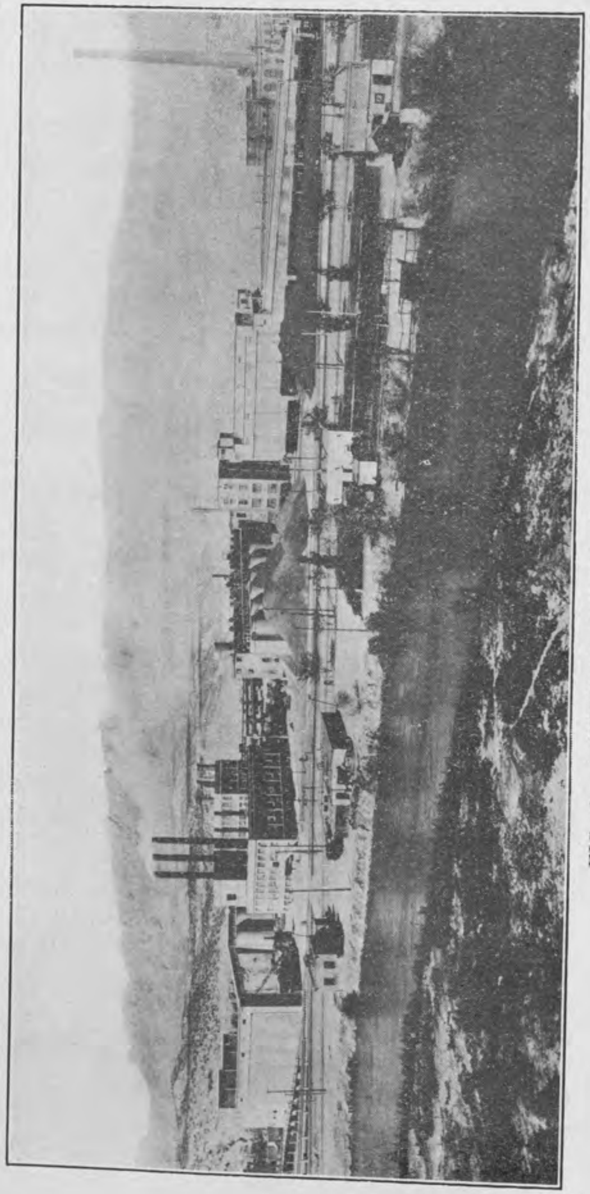


FIG. 1. A TYPICAL PORTLAND CEMENT PLANT

Field Work

The field work for this report was largely done during the summer of 1925. Incidentally, it may be noted that the author of this report, during the past six years has done geologic work in every one of the 120 counties of the State, and therefore, counties known definitely not to contain cement materials, were not visited during the summer of 1925. This elimination has saved the state both time and expense.

Laboratory Work

None of the laboratory work has been done by the author himself. It has all been executed in the Laboratories of the Experiment Station at Lexington, Kentucky, under the direction of Dr. A. M. Peter. Analyses of earlier years have also been investigated and some of these will appear in the chapter on Chemical Analyses later in this report.

Early History

The extensive use of concrete in recent years has led many to speak of the cement industry as a new industry and of the present age as the Age of Concrete. Hydraulic cement has been used in some form since the dawn of civilization. The Egyptians, more than 4,000 years ago, manufactured natural cement. Five hundred years before the beginning of the Christian Era, an aqueduct some seventy miles in length was constructed of natural cement to supply the city of Carthage with water. The Ancient Greeks and Romans used hydraulic cement in the foundations of many buildings, in super-structures, water mains, sewers and roads. The dome of the Panthenon, erected at the beginning of the Christian Era, is an example of the use of concrete construction by the ancients.

The art of manufacturing hydraulic cement appears to have been lost during the Middle Ages. In 1756, it was rediscovered by John Smeaton, who burned argillaceous limestones to manufacture a lime that would set under water. This material was used in the construction of the Eddystone lighthouse.

In 1796, Joseph Parker manufactured natural cement, which he styled Roman cement, by crushing and burning septaria nodules from the Isle of Sheppey, off the coast of England. In

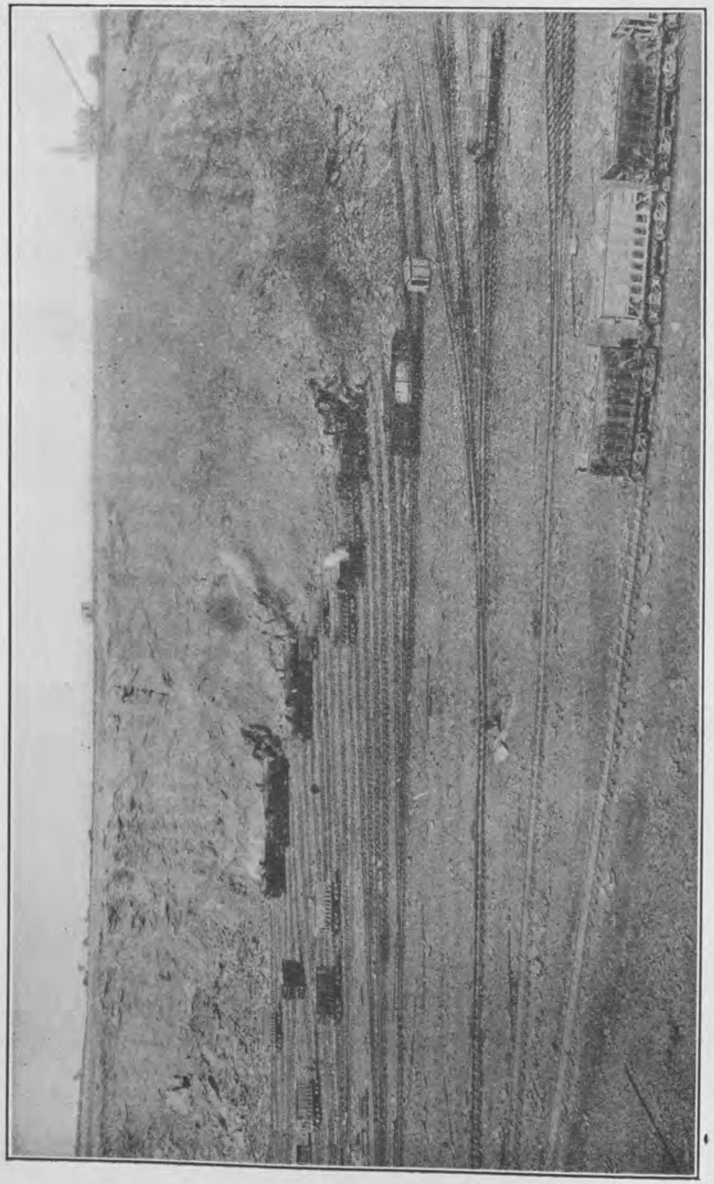


FIG. 2. A CEMENT LIMESTONE QUARRY

A scene in a typical limestone quarry which supplies one of the raw materials required in the manufacture of Portland cement.

1802, at Boulogne, France, natural cement was manufactured from septaria pebbles which were called Boulogne pebbles. In the interim from 1813 to 1818, M. Vicat manufactured hydraulic cement by mixing chalks and clays. In 1818, Canvass White produced natural cement from the hydraulic limestone deposits near Fayettesville, New York. Since that date hydraulic cement has been extensively manufactured in the United States.

In 1824, Joseph Aspdin manufactured Portland cement by calcining lime and clay. He styled the product Portland cement because the finished product closely resembled the famous oolitic limestone, like the oolitic limestones of Bowling Green, Kentucky, and Bedford, Indiana, has been extensively used for constructional purposes. In 1825, Aspdin established a plant at Wakefield, England, for the manufacture of Portland cement. In 1875, the first American Portland cement was manufactured by David O. Saylor, of Coplay, Pa. For the next fifteen years the development of the industry in the United States was very slow, but since the year 1890, the output has assumed large proportions. In 1923, the United States produced 137,000,000 barrels of cement, which was more than one-half the output of the entire world. The output of the world for the same year was 266,000,000 barrels.

Early History in Kentucky

According to the Louisville Courier-Journal under the date of March 9, 1923, the manufacture of cement in Kentucky was begun between the years of 1825 and 1830, at the time of the building of the Old Louisville and Portland Canal. Excavations for the canal uncovered deposits of argillaceous limestone suitable for the manufacture of cement. This limestone was burned after the fashion then in use for burning lime, and the burned product ground in a flour mill built by Louis and John Tarascon. These wealthy French brothers had spent over $150,000 in importing the most expensive flour mill machinery from France and erecting a six-story flour mill and millrace in Shippingport, a suburb of Louisville. This mill did double duty by grinding flour for the inhabitants of Shippingport and its immediate environs. The flour mill proved a losing venture because it was

too large for the requirements of the community and passed out of the hands of the Tarascons. It was used thereafter exclusively for the manufacture of cement.

The cement business grew steadily under the management of John Hulme, and likewise under the management of Speed and Rhorer. In 1866, by special act of the Kentucky legislature, the Louisville Hydraulic Cement and Water Company was incorporated. Milton H. Rhorer was elected President of the new company, Joshua F. Speed, Secretary, and the Louisville Savings Institution was named as Treasurer. In 1869, James B. Speed became superintendent of the plant which at that time had reached a capacity of 150 barrels of hydraulic cement per day.

Under the careful management of James B. Speed, the cement business grew so rapidly that it became necessary to erect a larger mill at Speed, Clark County, Indiana. This company also purchased another mill in the same locality. This mill had been in operation but a short time. Additions were made to these plants and the output of the combined plants was over 4,500 barrels per day. The Louisville Cement Company became recognized as the leading company in the manufacture of hydraulic cement in the United States.

In 1904, the Louisville Cement Company began the erection of a plant for the manufacture of Portland cement at Kosmosdale, Kentucky. On February 22, 1906, this mill was placed in operation with a capacity of 1,200,000 barrels of cement per year, and the company is now known as the Kosmos Portland Cement Company.

CHAPTER II.

TYPES OF CEMENT

The various cement materials used in modern constructional work may be listed as follows:

1. Non-hydraulic cements.
2. Hydraulic cements.

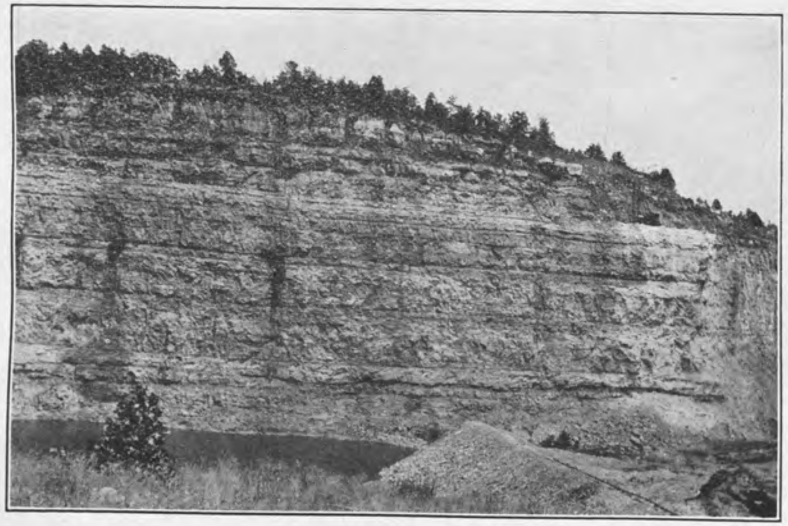


FIG. 3. GOOD WESTERN KENTUCKY LIMESTONE
F. W. Katterjohn quarry, Cedar Bluff, Caldwell County, Kentucky.

The first class consists of (1) Plaster of Paris, (2) Cement Plaster, (3) Keene's cement, (4) Common lime.

The second class consists of (1) Hydraulic lime, (2) Natural cements, (3) Portland cements, (4) Puzzolan or slag cement.

NON-HYDRAULIC CEMENTS

This group of cements is characterized by the fact that no member of the group possesses the property of setting or hardening under water. The first three are manufactured by burning gypsum, $CaSO_4$, $2H_2O$, at a comparatively low temperture, until one and one-half molecules of the water of crystallization have

have been expelled. The massive gypsum, rather than the variety selenite, which occurs in transparent plates, is preferred in the manufacture of Plaster of Paris. Variations in the process of manufacture producess common cement and Keene's cement.

FIG. 4. REMOVING CEMENT MATERIAL
Blasting for the new materials of portland cement. Great mountains of limestone are annually used to make the Portland cement used in this country. In 1923 14,000,000 pounds of explosives were consumed for this purpose.

Quick Lime

Quick lime, or common lime, is manufactured by burning pure or somewhat impure limestone, and grinding the burned product to an impalpable powder. In the process of burning the limestone, the carbon dioxide is driven off and lime, CaO, remains in the kiln. If the limestone contains more than 12 per cent of impurities, the burned product possesses the property of absorbing water with great avidity. This absorption is accompanied by heat and the evolution of caustic vapors, and finally the resulting product is a powder. The product is slaked lime.

Good lime hardens in the air. It comes in hard lumps. In the process of slaking, it increases in bulk, two and one-half to three and one-half times. It will absorb one-quarter its own

weight of water. When two much water is added in the process of slaking the lime, it forms a paste. Lime mortar is made by mixing slaked lime with sand. This product is used extensively for building purposes. If not enough water is added in slaking the lime, and more water is then added, it renders the lime granular and lumpy.

Lime Mortar

Lime mortar is manufactured by mixing a paste of slaked lime with two and one-half to three volumes of clean sand. The sand reduces the cost of construction, and prevents the mortar from cracking. If too much sand is used, the mortar will be porous. Two processes are involved in the hardening of the mortar: (1) The formation of crystals as the lime gradually dries out. (2) The formation of calcium carbonate or limestone through the absorption of carbon dioxide from the atmosphere.

Hydraulic Cements

Hydraulic Lime

Hydraulic lime is manufactured by burning a limestone which contains 10 per cent or more of silica and a sufficient amount of alumina to enable the burned product to set under water. There is usually present from fifteen to twenty-five per cent of silica and alumina combined. The burned product consists of free slaked lime, together with the silicates and aluminates of calcium.

The free lime slakes readily in water but the process is retarded by the presence of the silicates and aluminates. The material dries, hardens and slowly absorbs carbon dioxide from the atmosphere. When used under water, hydaulic lime sets with more or less rapidity. The larger the percentage of quick lime present, the slower will be the setting for common lime is inert under water and in damp soil. The setting is due to the presence of combined lime which suffers crystallization in the same manner as in hydraulic cement.

Natural Cement

American natural cement was first called Rosendale cement because it was first manufactured at Rosendale, New York. Its manufacture consists of burning hydraulic limestone

in plain, upright, kilns, with heat insufficient to cause vitrification, and subsequently grinding the product to a fine powder. The unground product will not slake with water. When the fine powder is mixed with water it hardens or sets rapidly both in air and in water. During the process of burning, the carbon

FIG. 5. PREPARING TO BLAST CEMENT LIMESTONE
Drilling dynamite holes in a limestone quarry. Drilling rigs resembling those seen in the oil country dig deep holes into which are placed the charges of high explosives.

dioxide of the limestone is driven off and the lime combines with the silicates, aluminates and ferrites of calcium. If the limestone is dolomitic, magnesium compounds will result. The percentage of magnesium carbonate in the limestone should not exceed 3.5 per cent.

Portland Cement

Portland cement may be defined as the product resulting from the calcination to insipient fusion of a properly proportioned intimate mixture of calcareous and argillaceous substances to which no addition greater than 3 per cent has been made, subsequent to calcination. Portland cement differs from natural cement both in the character of the raw material used and in the quantity of heat required in its manufacture. When the fine powder is mixed with water, chemical action takes place

and a hard mass is formed. The change the product undergoes is termed setting. This usually requires but a few hours at the most. On completion of the set a gradual increase in cohesive strength is experienced by the mass for some time and the cement gradually hardens. Cement usually require from six months to a year to gain their full strength. Portland cement differs from lime in that it hardens while wet and does not depend upon the carbon dioxide of the atmosphere for its hardening. Portland cement can be used under water as well as above water.

White Portland Cement

White Portland cement is manufactured from pure white sand, white quartz, white limestone, or ground marble. Although this white cement is about four times as expensive as ordinary Portland cement, it is extensively used in the United States.

Lewis and Chandler in their "Popular Handbook for Cement and Concrete Users" give the following summary of uses for white cement.

1. Building ornamentation. For exterior, steps, railings, columns, doorways, windows, casings, cornices, panels.
2. Stucco.
3. Concrete building blocks.
4. Interior decorations. Staircases, wainscoting, panels, reliefs, floors.
5. Statuary. An improved substitute for plaster in reproducing Statuary figures and groups for galleries of casts, or exterior and interior decoration.
6. Cemetery work. For monuments, vaults, columns, urns, etc.
7. Parks and grounds. For fountains, seats, railings, walks, bridges, etc.
8. Tile, mosaics, etc. In the production of white or delicate tints and as a cement in the place of Keene's cement.
9. Colored concrete. Permits the use of bright or delicate colors.
10. Painting iron or concrete.
11. Stainless mortar. For laying up Bowling Green limestone, Bedford limestone, sandstone or marble.
12. Setting or painting between blocks or slabs of white marble, limestone or brick.

Pozzuolana

Pozzuolana is often called slag cement. It is sometimes classified as Portland cement by the manufacturers. It differs materially from Portland cement. It is an excellent cement for

many purposes, but it possesses qualities that make it objectionable as a substitute for Portland cement in many classes of work. The cement will set either under water or in the open air. The product derives its name from the Italian city, Pozzuoli which is situated near the foot of Mount Vesuvius where the properties of cement produced by volcanic action were first discovered.

In the manufacture of Pozzuolana, blast furnace slags are used. The slag as it comes from the furnace is shorted by water under high pressure. In the rapid chilling of the slag, about one-third of its sulphur is liberated and the slag undergoes other chemical changes. The granulated slag is mixed with quick lime and ground to powder sufficiently fine for 95 per cent of the product to pass through a 200 mesh sieve. The slag is dried before grinding. The lime is obtained from a very pure limestone. Caustic soda is added in small quantities to the water used in slaking the lime to render the cement quick setting.

CHAPTER III.

Composition of Cement

According to LeChatelier, Portland cement consists of a mixture of tricalcium silicate, $3\ CaO,\ SiO_2$, and tricalcium aluminate, $3CaO,\ Al_2O_3$. LeChatelier arrived at this conclusion after a long series of experiments which consisted in examining thin sections of cement clinkers under the polarizing microscope.

Clifford Richardson, an American chemist, in a paper read before the Association of Portland Cement Manufacturers at Atlantic City, N. J., June 15, 1905, described the results of a thorough and exhaustive microscopic study of Portland cement clinkers. The results of Richardson's investigations are the most valuable of any yet produced as explaining the properties of Portland cement along the lines of physical chemistry. He arrived at the conclusion that Portland cement clinker is a solid solution. Richardson concludes that the chief element in Portland cement consists of colorless crystals of rather strong refractive power, but of weak double refraction. By this is meant that the crystals in polarized light between crossed Nicol prisims posses insufficient optical activity to produce more than weak interference colors of a bluish-gray hue. Richardson further concludes that this chief component of Portland cement consists of a solid solution of tri-calcic silicate in tri-calcic aluminate.

According to Richardson, there is also a constituent present that fills the interstices between the other constituents. It is of a brownish orange color and forms the magma or liquid of the lowest freezing point out of which the chief component of cement crystallizes. It is strongly double refractive, giving brilliant colors when examined between crossed Nicol prisms. This solid solution of di-calcic slilcate in dicalcic aluminate is apparently miscible with the tri-calcic silicates and aluminates while in a molten condition but not so in the solid form.

Richardson also concludes that the setting of Portland cement is almost entirely due to the decomposition of the tri-calcic silicates and aluminates and that the strength of the cement after setting, is due entirely to the crystallization of cal-

cium hydrate under certain favorable conditions, and not at all to the hydration of the silicates and aluminates.

Components

The components usually found in Portland cement are: (1) Lime. (2) Silica. (3) Alumina. (4) Ferric oxide. (5)

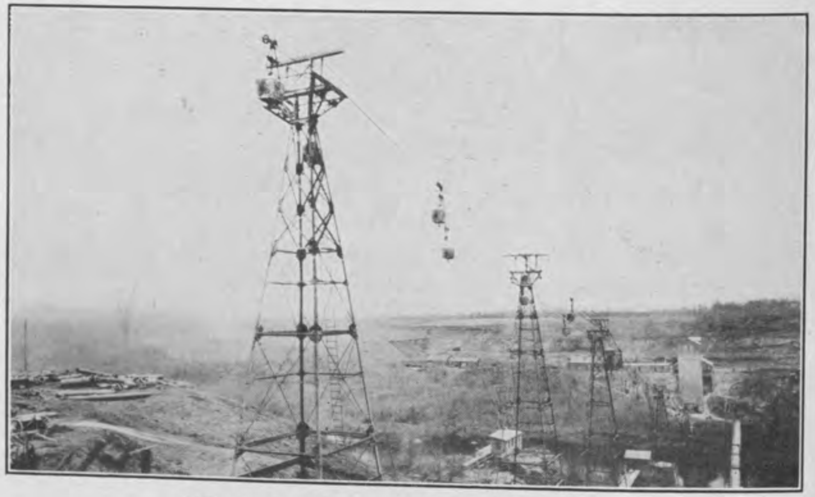


FIG 6. RAW MATERIALS CONVEYOR
An aerial tramway for conveying the raw materials from the quarry to the plant at a mid-western Portland cement mill. While railroads are usually used for this purpose, where the ground is too uneven the above method has proved satisfactory.

Mangesia. (6) Alkalies. (7) Sulphur. (8) Carbon Dioxide. (9) Water. (10) Titanic Acid. (11) Ferrous oxide. (12) Manganous Oxide. (13) Phosphorus pentoxide. (14) Strontium Oxide.

The first three components are essential in all Portland cement. The last five are minor accessory constituents. It is doubtful if they have any effect upon the hydraulic or setting properties of Portland cement.

Lime

In a table of the analyses of thirteen samples of American Portland cement, as made and given by R. K. Meade, the percentage of lime CaO, varies from 60.25 to 63.95. It is often said that good cement may fall as low as 58 per cent in its lime con-

tent and reach as high as 67 per cent. The average lime content for rotary kiln cement is 63 per cent. The percentage of lime present is dependent upon (1) The percentage of silica, (2) The percentage of Alumina, (3) The care with which the cement has been manufactured. Up to a certain limit, the more lime that is present, the greater will be the strength of the cement.

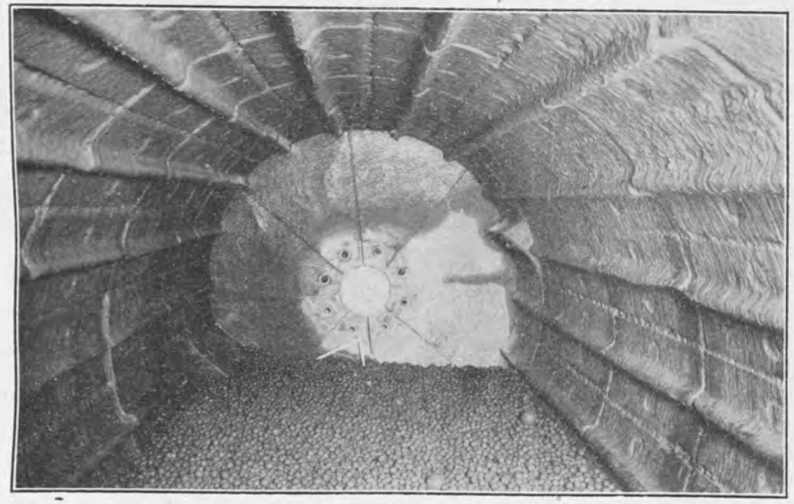


FIG. 7. INSIDE OF A TUBE MILL
The rotary action of the mill carries the small balls partially up the side where they fall in a cascade of steel that grinds the raw materials or the clinker into a powder finer than flour.

However, when more lime is present than can combine with the silica and the alumina, the cement is weak and liable to crack. High lime cements are slow in setting and rapid in hardening Low lime cements are apt to be quick setting and weak. Such cements usually contain an excess of clay which is devoid of cementing properties. The percentage of lime required in a given cement can be controlled by the setting time and the soundness desired.

Silica

Silica stands second in importance among the essential components of Portland cement. It stands next to lime in the percentage present. The range is normally between 19 per cent and 25 per cent. In thirteen samples of American Portland cement

analyzed by R. K. Meade, the range in silica varied from 20.32 to 22.71 per cent. Cements low in silica are usually high in alumina, and those high in alumina are low in silica. High silica cements are usually slow setting and of good tensile strength. A good cement should contain 2.5 times as much silica as alumina.

The silica in cement may be derived from the following sources: (1) The silica of the Kaolinite particles in the clay, (2) The silica of other silicates constituting the clay, (3) The free uncombined silica grains in the clay, (4) Silica grains in the limestones used and at times diatoms in the marls used in the manufacture of cement. The free silica must be present in such a fine state of subdivision that it can easily combine with the lime required. The silica content of cement can not be increased by the addition of quartz or flint to the raw materials. It can, however, be increased by the addition of (1) A more siliceous clay, (2) A more siliceous shale, (3) A more siliceous cement rock. One or more of the above should always be intimately mixed with a high alumina clay.

The third essential component of Portland cement is alumina. It ranks third in the percentage present. Usually the content of alumina present is between 5 per cent and 10 per cent. In the thirteen samples of American Portland cement analyzed by R. K. Meade, the alumina ranges from 5.91 per cent to 8.12 per cent. High alumina cements are quick setting. If the percentage of alumina rises above 10 per cent, the cement is very quick setting. There is also a corresponding decrease in the tensile strength. Therefore, cements containing more than 10 per cent alumina are to be avoided. The strength of cement is due to the calcium silicate present and the setting properties to the calcium aluminate.

The alumina in the cement may be due to (1) The alumina in the Kaolinite grains. (2) The alumina in other alumina silicates in the clays used. (3) The impurities containing alumina in the limestones used. (4) The impurities containing alumina compounds in the marl used.

Ferric Oxide

The ferric oxide found in cements may be regarded as a major accessory constituent. The amount present is usually less

than 5 per cent, unless a cement high in ferric oxide is especially prepared, for some particular purpose. In the table of the thirteen analyses of American Portland cement as made by R. K. Meade, the ferric oxide ranges from 2.15 per cent to 2.81 per cent. In these cements it is a fairly constant constituent.

FIG. 8. COAL A FACTOR IN CEMENT MAKING

During 1923 it is estimated that over 10,500,000 tons of coal, in addition to vast quantities of oil and natural gas were consumed by the Portland cement industry. Adequate conveying equipment is necessary to facilitate handling the great amount of coal consumed by the average plant.

The source of the iron oxide in the cement may arise from: (1) The iron in the various silicates constituting the clays used. (2) Iron oxides and hydrous oxides occurring as impurities in the clays used. (3) Iron compounds occurring as impurities in the limestones and marls used. (4) Iron oxides intentionally added to lower the temperature at which clinkering takes place, and make it easier to produce a sound cement. The presence of the iron oxides in the cement mix acts as a flux and promotes the combination of the silica and the lime. High iron cements are often recommended for use in sea water on account of the resistance of such cements to the corrosive action of various salts held in solution in sea water.

High iron cements can usually be recognized by their dark, gray color.

Magnesia

According to Professor Robert Fletcher, for many years Director of the Thayer School of Civil Engineering at Dartmouth College, limestones containing magnesium carbonate content not exceeding 3.5 per cet. can be used with safety in the manufacture of Portland cement. If the content falls between 3.5 per cent and 5 per cent, some limestone free from magnesia must be used with it to lower the magnesia content of the finished product. Limestones containing more than 5 per cent magnesium corbonate should never be used in the cement industry.

For a long time, 1½ per cent magnesia in the finished product was considered dangerous. At the present time, even 4 per cent is considered harmless, while some authorities allow even 5 per cent magnesia.

The magnesia present in Portland cement may arise: (1) From the presence of magnesium bearing silicates in the clays used. (2) From the use of dolomitic limestones in the mix. (3) From magnesium carbonate intentionally added to replace a part of the lime.

In the thirteen analyses made by R. K. Meade, and above cited, the range in magnesia is from 0.81 per cent to 3.71 per cent. Whether magnesia should be considered in calculating cement mixtures or not is a debatable question. The question really is whether or not the magnesia is combined with the silica and alumina in the cement. Even if combined with the silica in the formation of silicates, such silicates are inferior to the more active lime silicates. Standard specifications place the amount of magnesia allowable at the present time in Portland cement at 4 per cent.

Alkalies

Soda and potash are present in all cements. The percentage is usually very low, less than 0.75. The percentage of alkalies may reach as high as 2.75 per cent in cements made from alkali waste, but such cements do not give satisfactory results. The soda is in excess of the potash, because the potash is the more volatile of the two alkalies and more readily burned out in the kiln. The effect of the alkalies is to render the cement quick

setting. In some instances, quantities of the carbonates or the hydroxides of sodium and potassium have been used to make a given cement set more quickly.

Sulphur

The chief sulphur bearing compounds in cement are calcium sulphide, CaS, and calcium sulphate, $CaSO_4$. This sulphur may arise from several different sources: (1) The presence of sulphides as impurities in the limestone or marl used. (2) The presence of sulphides as impurities in the clays used. (3) The addition of gypsum to the clinker before grinding. (4) The addition of Plaster of Paris after grinding but before shipping, or in same instancees before grinding. (5) The addition of dead burned gypsum.

The percentage of gypsum added to Portland cement varies from 2 per cent to 3 per cent. Its function is that of a retarder. The setting time of Portland cement can be largely controlled by the use of gypsum or Plaster of Paris. The standard specifications allow 1.75 per cent of sulphur trioxide in Portland cement. In the table of thirteen analyses of Portland cement as made and published by R. K. Meade, the sulphur trioxide content varied from 1.02 per cent to 1.59 per cent. While these low percentages of sulphur content retard the setting time of the cement, promote soundness and are beneficial, the addition of more than 3 per cent of calcium sulphate either as gypsum or Plaster of Paris is injurious. Approximately 750,000 tons of gypsum are utilized annually as a retarder in the Portland cement industry.

Carbon Dioxide

Carbon dioxide is present in all cements. It may arise from different sources: (1) From the limestone used in the manufacture of the cement, (2) From the marls used in the manufacture of the cement, (3) Through the absorption of carbon dioxide from the atmosphere after the grinding of the clinker.

This component of cement is subject to a considerable variation in percentage. In well seasoned cements, the percentage of carbon dioxide is much higher than in freshly ground cements In Analysis it is determined with the water as loss on ignition.

Water

Water is always a minor accessory constituent in Portland cement. Like the carbon dioxide, it is subject to considerable variation. Aged or well-seasoned cements have absorbed some water from the atmosphere and therefore are higher in their water content than freshly burned and ground cements. Some

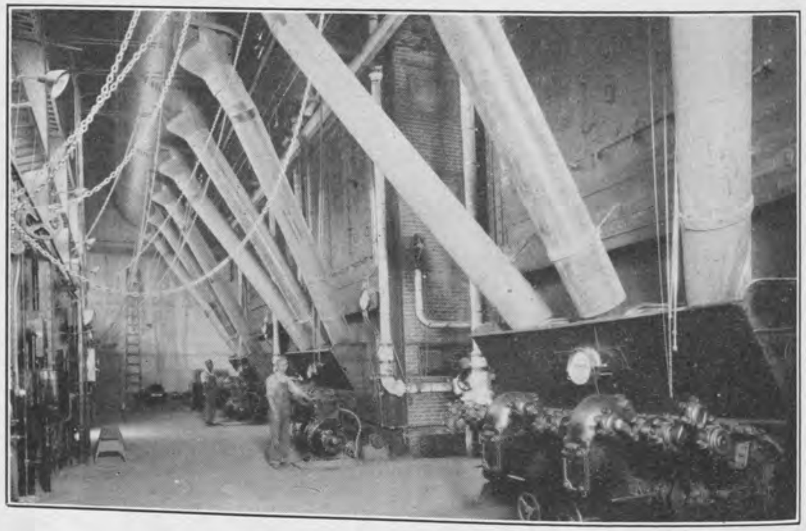


FIG. 9. CEMENT MAKING A POWER CONSUMER
A boiler room in a Portland cement plant. The Portland cement industry has been rated as the tenth largest industry in point of installed power. Some of the larger mills daily consume as much power as a city of 100,000 inhabitants.

of the water may be expelled at 110 degrees C, and is therefore hygroscopic, while a part of the water requires a red heat for its expulsion and therefore represents the water of crystallization. As noted above, the water is determined with the carbon dioxide as the loss on ignition. In thirteen samples of American Portland cement analyzed by R. K. Meade, this loss varied from 0.83 per cent to 3.55 per cent. Standard specifications place no restrictions on the percentage of loss on ignition for Portland cement.

CHAPTER IV.

Raw Materials

The essential components of Portland cement are lime, CaO, silica, SiO_2, and alumina, Al_2O_3. To this list some authors would add ferric oxide, Fe_2O_3. Silica occurs abundantly in nature as the mineral quartz, and less abundantly as flint and chert, but these forms of silica are not suitable for the manufacture of Portland cement. Alumina occurs as the mineral corundum and with ferric oxide as emery. Corundum is No. 9 in the scale of hardness and it is very difficult to reduce corundum or emery to the degree of fineness necessary for combining at high temperatures with the lime to form the tri-calcic aluminate which is one of the essential compounds in all Portland cements. Although the essential components of the raw materials are widely distributed in nature, it does not follow that all deposits containing these minerals can be used in the cement industry. The silica and alumina do occur in combination with each other in widely distributed clays and shales in various combinations well suited for the cement industry. Lime can not occur free and uncombined in nature for it absorbs carbon dioxide from the atmosphere and passes into the carbonate. The limestones, essentially $CaCO_3$, are widely distributed in nature but all limestones are not well suited for the manufacture of Portland cement.

Classification of Materials

The various materials entering into the manufacture of Portland cement either directly or indirectly may be listed as follows:

1. The cement materials proper, which are utilized in the actual mix.
2. The fuels used to burn the mix and to furnish power for the plant.
3. The fluxes used to aid in the fusion and the retarders used to control the time of setting.

Cement Materials Proper

The chief components used in the manufacture of Portland cement may be subdivided into two main classes: (1) The calcareous. (2) The argillaceous. The calcareous materials may be further subdivided into: (1) Limestone. (2) Marl. (3) Chalk. (4) Alkali waste. (5) Cement rock.

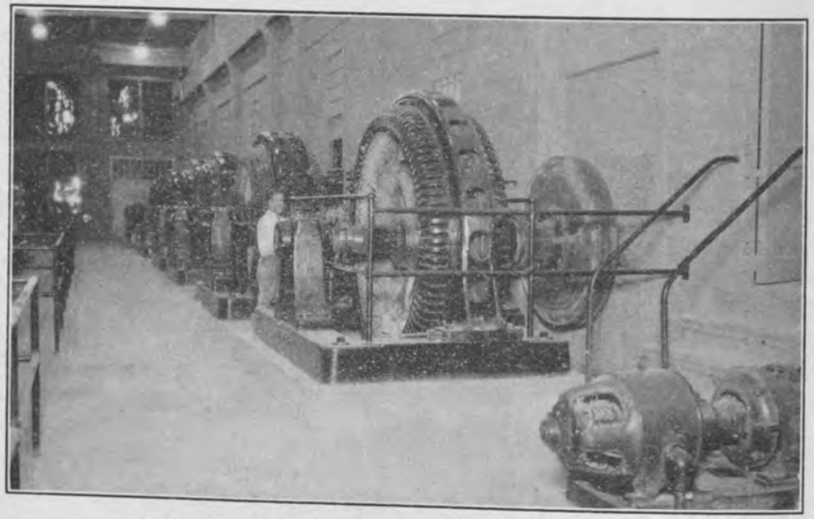


FIG. 10. MODERN ELECTRIC DRIVEN MILLS
A battery of electric motors operating grinding mills. Some of these motors required to operate a ball and tube grinding mill are as much as 500 and 600 H. P.

The argillaceous materials may be subdivided into: (1) Clay. (2) Shale. (3) Slate. (4) Blast furnace slag.

It is apparent that any combination of the various constituents of the two major groups that will give a burned product which will conform to the standard definition of cement as given in Chapter II, can be used in the manufacture of Portland cement. However, in actual practice, the following combinations have been selected.

1. Limestones and clays or shales.
2. Limestone and the impure limestones known in Pennsylvania as cement rock.
3. Marl and clay or shale.
4. Blast furnace slag and limestone.
5. Caustic soda waste and clay.

Limestone

Limestones consisting essentially of calcium carbonate, $CaCO_3$, are widely distributed in nature. Their varieties are many and their modes of origin widely varied. Perhaps the most abundant source is the accumulation on the sea floor of the calcareous remains of foramanifere, mollusks and corals.

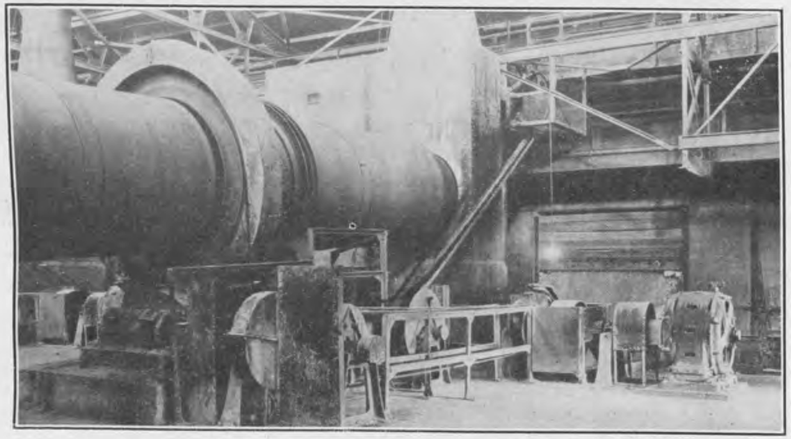


FIG. 11. HUGE DRYERS USED IN PROCESS
In the dry-process Portland cement plants huge rotary dryers are necessary to remove the latent moisture of the raw materials. Other plants use the wet process in which the raw materials are mixed with water into a slurry.

Broken shells may be cemented together to form limestone. A direct precipitation of calcium carbonate can occur only when the supply of the carbonate is in excess of that which can be consumed by living organisims and when the conditions of temperature and pressure are such as to expel the solvent, CO_2. Chara and mosses are capable of extracting carbon dioxide and setting free calcium carbonate. Algae may exert a potent influence in the formation of marl deposits. Albumen, which is present in the organic parts of all aquatic plants, may serve as a precipitating agent for calcium carbonate.

As the calcium carbonate suffers crystallization through heat and pressure, the material passes into a marble. A marble which is a metamorphosed limestone is usually harder than a somewhat impure limestone and therefore more difficult to reduce to the degree of fineness required for the cement mixture.

Marl

In composition, marls are essentially calcium carbonate, $CaCO_3$, but occasionally they carry an appreciable quantity of clayey matter. They owe their origin to the direct or indirect action of vegetable or animal life, and in part to purely physical and chemical causes. The calcium carbonate is mostly in a fine granular form, but it often carries numerous fresh water shells and shell fragments. Their home is around the borders and on the bottom of fresh water lakes. To secure the proper percentage of the cement mixture, marls require a larger per cent of clay than the impure limestones would demand.

The term marl has been applied to shales that are not calcareous and to the green sand of New Jersey and Virginia which is a hydrous silicate or iron and potassium. The percentage of calcareous and clayey matter in the green sands is very small. The above types sometimes listed as marl should not be used in the cement industry.

Chalk

As used in the Portland cement industry, the term chalk is applied to both chalk beds proper and to soft chalky limestones. The chalk beds are practically pure calcium carbonate, which results from the accumulation of shells, mostly foraminifera. The chalky limestones are very soft and therefore like chalk itself are easily crushed and pulvarized for the cement mixture. If their chemical composition and ease with which they are pulverized are alone considered, they constitute an ideal cement material. The chief objection to them is their ability to absorb water during a rainy season.

Alkali Waste

Alkali waste, which consists essentially of calcium carbonate obtained from the manufacture of caustic soda, has been utilized in the manufacture of Portland cement, both in the United States and in Europe. The calcium carbonate derived from the Leblanc process used in the manufacture of caustic soda, usually carries too high a percentage of sulphides to be used to advantage in the cement industry, but the calcium carbonate derived from the manufacture of caustic soda by the ammonia

process is usually quite pure. The chief objection to it is that it frequently carries an appreciable quantity of calcium hydroxide, $Ca(OH)_2$.

Cement Rock

This term has been applied for many years to the impure clayey limestones used so extensively in Pennsylvania and elsewhere in the manufacture of Portland cement. In the Lehigh Valley in Pennsylvania this impure, clayey limestone approximates, in composition, to 75 per cent carbonate of lime, 18 to 20 per cent of clayey matter, with approximately 5 per cent of non-essential components. If the limestone contains less than 75 per cent calcium carbonate, it is then enriched by the addition of the proper amount of some very pure limestone. If it contains more than 75 per cent carbonate of lime, then enough clay or even slate is added to make the correct percentage in the cement mixture.

Cement rock is much softer than many pure limestones and is therefore more easily crushed and ground to the degree of fineness desired. It, therefore, is less expensive to manufacture the cement. If the contents of cement rock are not in the correct proportions is is usually cheaper to add a little clay where clay is needed than it is to add purer limestone where limestone is needed, for cement rock is often overlaid with clay deposits that can, in part at least, be utilized.

Clay

The term clay is one that scarcely admits of a concise definition. It is one of the many substances which result from the decomposition of different types of rock. It is generally fine grained, unconsolidated and when wet it is more or less plastic. It loses the property of plasticity when strongly heated and becomes exceedingly hard.

Kaolinite is often referred to as the base of clays. It is a hydrous silicate of aluminum, of formula $2H_2O$, Al_2O_3, $2SiO_2$. It is often associated with its ferric equivalent, nontronite, whose formula is $2H_2O$, Fe_2O_3, $2SiO_2$. There is also present a certain amount of finely divided free silica, either as quartz or opal, lime and magnesium compound, iron oxides, together with minor silicates containing sodium and potassium.

Two factors are of considerable importance in determining the fitness or suitability of a given clay for the manufacture of

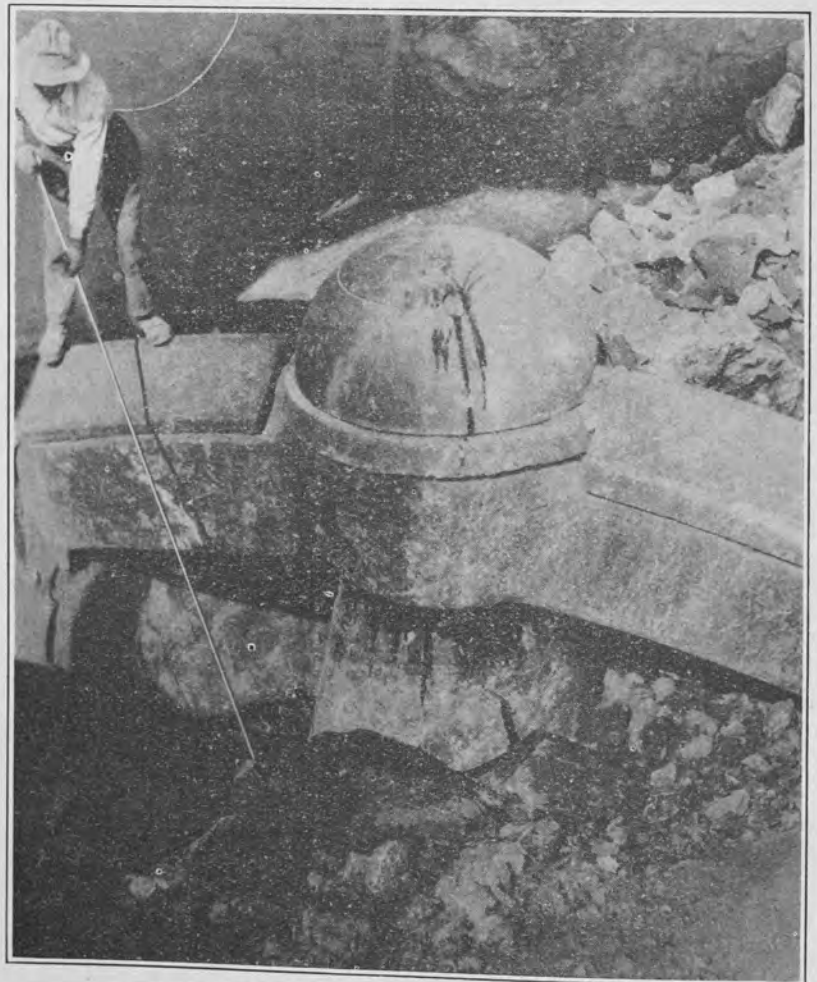


FIG. 12. MAMMOTH CRUSHER BREAKING ROCK
When the raw materials come from the quarry of a Portland cement plant the first step is to crush them to a size that will pass a 7 or 8 inch ring. This is accomplished in a gyratory crusher.

Portland cement: (1) The actual chemical composition. (2) The state of subdivision of the silica grains. These should pass a 100 mesh sieve.

The actual ratio desired between the silica and the alumina is 2.3 to 1. Iron may replace the alumina in a large measure without injury to the resulting cement. The higher the lime content, the better, for it diminishes the amount of limestone that must be added. The lower the magnesium content, the better, and should never exceed 3 or 4 per cent. The alkalies should not exceed 3 per cent, for with a higher alkali content, the mixture would produce an unsound and quick setting cement.

SHALE

Shale is a consolidated mud or clay, in which the silicates of aluminum are the most important and characteristic constituents. In texture, it is fine grained. In structure, it is laminated and fissile. The term shale has been used to embrace a wide variety of sedimentaries that present a shaly structure. Sand grains by wave action may be reduced to an impalpable powder and these consolidated flour-like particles may present a shaly appearance. In the presence of clayey matter, such rocks pass into argillaceous sandstones. Grains of calcite may be rendered correspondingly minute and consolidated into a shaly rock. In the presence of clayey matter the stone is best classified as an argillaceous limestone. In selecting shales for use in the manufacture of Portland cement, it is necessary to observe all the conditions mentioned under clay, and for the same reasons there given. Shales, when properly pulverized, will mix better with limestone than with marls because their psysical characteristics are more nearly in common. For the same reason, clays will mix better with marls.

SLATE

Geologically considered, a slate is a metamorphosed clay or shale. It may or may not have paused at the shale phase. Commercially, a slate denotes a rock which possesses fairly perfect cleavage, adapting it to commercial uses for which other types of building stone are not well suited. Usually its mineral composition can be distinguished only with the aid of the microscope. It differs physically from a shale in that it has perfect cleavage and has been subjected to a considerable amount of pressure. It differs chemically from a shale in that it is richer in silica and ferrous oxide. The chemical composition of sedi-

mentary slates is fairly constant. In fact the composition of slates seems to vary no more widely than the composition of shales. If slates are used in the manufacture of Portland cement, the same rules should be observed as in the case of clay and shale.

The waste of slate in the slate industry often represents 75 per cent or even more of the quarried product. Much of this material is of the proper chemical composition for use with limestone in the manufacture of Portland cement. It can displace either clay or shale in the cement mix.

As the removal of this refuse material increases the profits in the slate industry, the slate can often be obtained at the mere cost of hauling the material to some cement plant near the slate quarry.

Blast Furnace Slag

Two kinds of cement are manufactured from blast furnace slag. (1) Portland cement and (2) Pozzuolana.

In the manufacture of the true Portland cement with blast furnace slag as one of the constituents in the mix, the slag is mixed with limestone. The mix is ground to a very fine state of subdivision and then burned in the same manner as the mix would have been burned had the clay or shale been used instead of slag.

Pozzuolana is often called slag cement. In the manufacture of Pozzuolana, blast furnace slags are used. The slag as it comes from the furnace is shorted by water under high pressure. The granulated slag is mixed with quick lime and ground to a powder sufficiently fine for 95 per cent of the product to pass through a 200 mesh sieve. The cement will set either under water or in the open air.

The iron ores from which the slag is obtained should be pure ores like those of the Lake Superior district and the limestone used in fluxing the ore should be non-dolomitic.

Fuels

Fuels are used in the Portland cement industry both in the burning of the raw materials used in the cement mixture and for

power. The source of fuel is practically as important a question to settle in locating a cement plant as the source of the

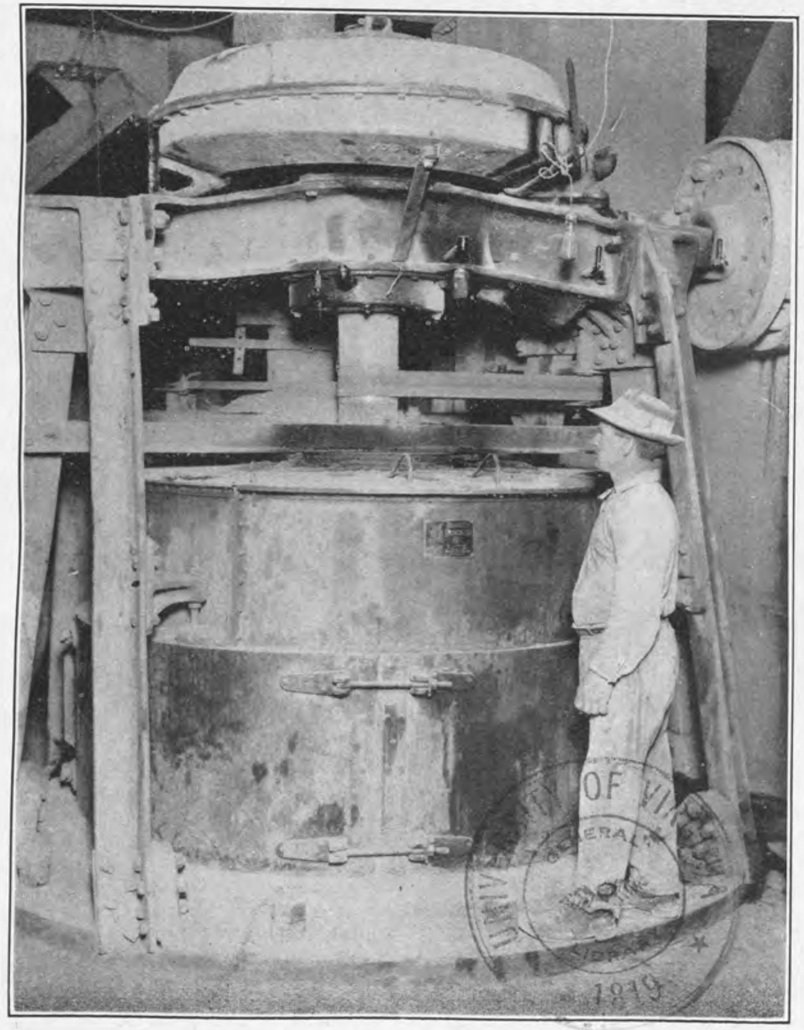


FIG. 13. SPECIAL TYPE GRINDING MILL
A centrifugal type of grinding mill seen in many Portland cement plants.

limestone and clay to be used in the mix. Most plants require fuel for power as well as for burning the mix. A few western plants use hydroelectric power.

Coal

Bituminous coal is the fuel in general use in rotary kilns burning cement mixtures. The coal is generally slack, but it may be the uncrushed or run-of-mine coal. If the latter is used, it must be pulverized before use in the kiln. The finer the state of subdivision of the coal, the smaller the tonnage of coal required.

The coal, whether gas slack or run-of-mine, should meet the following requirements:

Fixed carbon, 45-60 per cent. Volatile and combustible matter, 30-45 per cent. Ash, less than 10 per cent. One half ton of coal or its equivalent is required for every ton of cement manufactured.

Sulphur is an objectionable impurity in the coal. In coal it occurs in combination with iron as the disulphide, FeS_2, which is 6.25 in hardness and not easily pulverized, therefore, some of the grains of pyrite fall into the clinker and produce not only a weaker cement but one that develops on exposure an objectionable iron stain. In 1923, 10,500,000 tons of coal were consumed in the cement industry. 7,000,000 tons were pulverized for burning in the kilns.

Oil

Crude oil has been used as a fuel in the Portland cement industry. Its cost per ton of cement manufactured has been higher than the cost where coal is consumed. In localities somewhat removed from a coal supply and in close proximity or within a permanent oil field, oil may be used to a good advantage. In 1923, 4,700,000 barrels of oil were used in the cement industry.

Gas

If a plant for the manufacture of Portland cement is located near or within a permanent gas field, then gas can be used in burning the clinker. Otherwise, bituminous coal is preferred. In 1923, 4,000,000,000 cubic feet of gas were consumed in the cement industry.

Fluxes and Retarders

Fluxes

Perhaps the use of fluxes in the Portland cement industry is of such minor importance that it should not be mentioned in a report as terse as this on the cement materials of Kentucky. Yet, fluxing materials of one kind or another have often been added to the raw mixture to lower the fusion point required in the formation of the clinker, and in the formation of new compounds of the silica and alumina with the limes. The advantage gained by the use of fluxes is doubtful, save where a plant is compelled to use poor material, such as : (1) A limestone rich in its silica content. (2) A clay too high in its silica content. (3) A clay too rich in alumina. Even where these conditions obtain, it may be more advantageous to seek a new source of good material. Iron oxides, or limonite, cryolite, sodium and potassium compound are common fluxes in the cement industry.

Retarders

Some sulphate is always added to Portland cement to control the time of setting. Rotary kiln cement is so quick setting that some retarder is always necessary. The retarders in general use are:

1. Gypsum, $CaSO_4$, $2H_2O$.
2. Plaster of Paris, $(CaSO_4)_2$, H_2O.
3. Rarely, Dead burned plaster, $CaSO_4$.
4. Sulphuric acid, H_2SO_4.

Gypsum is used when the retarder is added to the clinker before the grinding of the cement. It should not be added in excess of 3 per cent, for beyond that point, the retarding influence is much less marked, and the cement is decidedly weaker. Gypsum is cheaper than Plaster of Paris and therefore it is used in nearly all cement plants in the United States.

Plaster of Paris is manufactured by burning gypsum, $CaSO_4$, $2H_2O$, until 75 per cent of its water has been expelled and a new compound formed which may be expressed as $(CaSa_4)_2$, H_2O. This loss of water occurs at a temperature of 132 degrees. If the temperature is raised to 343 degrees, all of the water of crystallization in the gypsum will be expelled and the product is known as dead burned plaster.

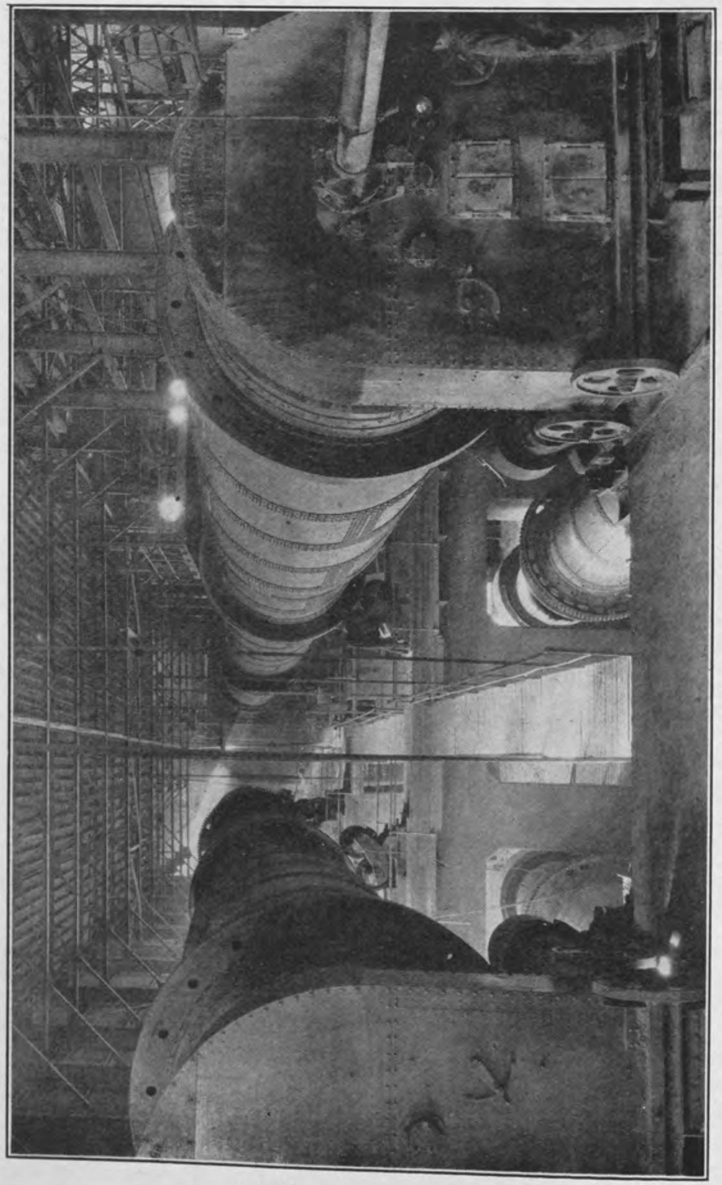


FIG. 14. BATTERY OF ROTARY KILNS IN CEMENT PLANT

These kilns are as long as five freight cars and weigh as much in operation as ten all steel Pullmans. They are rotated about one turn in every minute and a half. In these kilns the finely-ground properly-proportioned raw materials are converted into a material of new physical and chemical properties known as clinker. This clinker emerges from the lower end of the kiln in the form of white hot marbles. A temperature between 2,500 and 3,000 degrees Fahrenheit is necessary for this conversion process.

Plaster of Paris is added to the ground clinker at the storage house, while the cement is being packed. It is essential that the burned gypsum or Plaster of Paris should be very finely pulverized before using, for the finer the state of subdivision of the Plaster of Paris, the better will be the results obtained.

The difficulty encountered in the use of dead burned plaster in the cement industry is the cost required to liberate all the water of crystallization in the gypsum. It would require a smaller tonnage than gypsum to produce the required effect upon the cement, but the cost would be far greater.

Sulphuric acid can be added as a spray to the cement clinker and produce the desired retardation of setting, but sulphuric acid is too expensive at the present for practical use as a retarder in the Portland cement industry.

CHAPTER V.

MANUFACTURE OF CEMENT.

The term Portland cement is used to designate the artificial product formed by burning a mixture of limestone and clay, or limestone and cement rock, or marly and clay, or chalk and clay, to the point of incipient fusion. Portland cement differs from natural cement both in the character of the raw material used and in the quantity of heat required in its manufacture.

There are five steps involved in the process of manufacturing the cement: (1) The quarring of the limestone and cement rock. (2) The grinding of the raw materials. (3) Proportioning and mixing. (4) Burning the mixture. (5) Grinding of the clinker.

Quarrying

The limestone and the cement rock are quarried by the open cut method as in the granite and marble industry. In these industries, explosives are to be avoided as they tend to induce insipient fractures that favor a more rapid disintegration. In the cement industry, explosives, like dynamite, nitroglycerene, rendrock, dualine and giant powder may be used to loosen and break up the limestone and cement rock. Probably 95 per cent of the raw materials used in the cement industry are quarried products.

The material is usually shipped direct to the mill as quarried. It is often broken down by sledging into blocks of convenient size for loading. Sometimes steam shovels are used in the loading. In some shale deposits, the steam shovel does both the excavating and the loading. In a few instances, the limestone and cement rock are sent through rock crushers at the quarry and sent to the mill as crushed stone. In a few instances, driers are used at the quarry and the raw material shipped as dried stone to the mill.

Mining

This method of obtaining the raw materials for the cement industry does not include more than 2 per cent of the amount used. In this process the raw materials are obtained by under-

ground methods through shafts and tunnels. It is an expensive method that adds cost to the raw materials, but it has its own advantages. (1) The mine can be operated at all seasons of the year. (2) The workmen are protected from storms. (3) The temperature is more nearly the same in summer and winter.

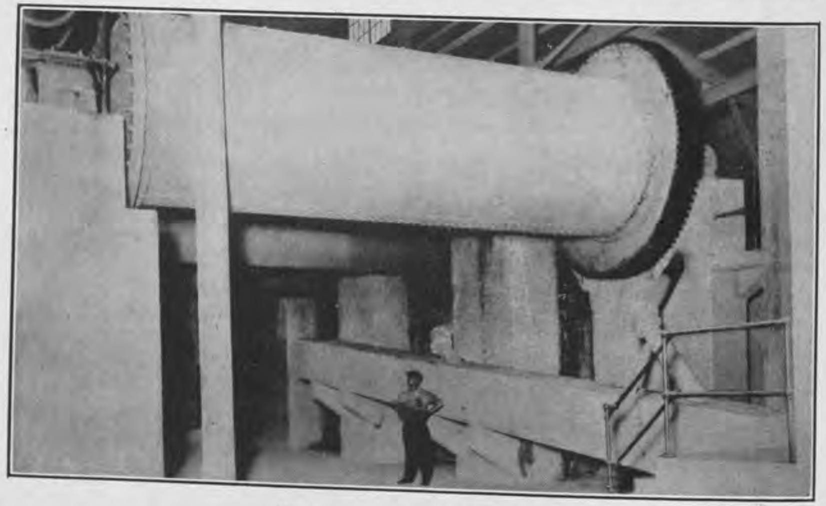


FIG. 15. A TUBE MILL
It is used for grinding in a Portland cement plant. This type of grinding equipment is used in many plants for grinding both the raw materials and the clinker.

(4) The raw materials as they come from the mine are dry. (5) The raw materials are clean, that is, free from the admixture of foreign matter.

Dredging

Approximately 3 per cent of the raw materials used in the cement industry are obtained by dredging. Marl is usually excavated by this method for marl not only carries much diffused water, but is often covered by water, sometimes to a considerable depth. Borders of marl deposits are often out of water and could be handled by a steam shovel, but in the rainy season this would be difficult. Marl deposits and at times clay deposits are partially drained before dredging begins. As marls and some clay deposits lie in depressions at a lower level than the mill, gravity does not transport the dredged product. There are three methods of haulage in general use: (1) Haulage on cars

by horses. (2) Haulage in cars by steam power. (3) Haulage on cars by electric power.

Grinding

F. W. Kelley, President of the Portland Cement Association of America, stated in 1924, "That the manufacture of Portland cement as carried on in the United States, is an exact chemical-mechanical process, in which large quantities of raw materials are first combined in the right chemical proportions, and are ground to extreme fineness. The proportioning of the material is accomplished in machines, under the constant control of chemists. The grinding is generally done in several stages by machines, each suited to the particular kind of material handled, and to the fineness to be reached. The raw materials when prepared and standardized chemically and physically, are in all cases fed into rotary kilns."

In the grinding of the raw materials, three processes have been extensively used: (1) The wet process. (2) The semi-wet process. (3) The dry process.

The wet process is better for soft or wet materials as marl and clay, or chalk and clay. The materials are mixed in a vat or wash mill with a large excess of water. The lumps are reduced by agitators to a finely divided state so that the material may be held in suspension in the excess of water. The sediment is drawn off into settling tanks and molded into bricks which are dried and calcined in either stationary or rotary kilns.

In the semi-wet process, the marl or chalk is disintegrated and run into storage basins. The clay is dried, pulverized and mixed with the proper amount of marl in pans. Enough water is added to this mixture to produce a thick, creamy mass. The mixture is then ground and run into tanks where it is constantly stirred by means of pedals or compressed air. The wet slurry is pumped into rotary kilns where it is burned at a high temperature.

In the dry process, the limestone and cement rock are crushed, mixed, dried, ground, calcined and the clinker ground to a powder.

The Hudson and Catskill plants in New York use the dry method entirely. The limestone, clay and the fuel, which is bituminous coal, are each ground separately. The limestone and

clay are mixed and fed into the upper end of a rotary kiln. The coal is blown in from the lower end of the kiln. The clinker secured by this dry method ranges in size up to that of a man's head. The clinker is cooled by being carried back and forth on an endless steel conveyor and finally dumped into a crusher,

FIG 16. GOOD CENTRAL KENTUCKY LIMESTONE
Upper portion of Ripy Brothers quarry, High Bridge, Anderson County, Kentucky.

from which it goes to the fourth set of grinders. Water is not used at any time in this process.

The raw material is usually ground to a degree of fineness that 95 per cent of product will pass through a 100 mesh sieve. This degree of fineness is required for sound cement. In a few instances a slightly lower degree of fineness has been selected. The two advantages of a fine grinding are: (1) It requires less coal to burn the product to a clinker. (2) It favors a more rapid combination of the lime with the silica and alumina in the formation of silicates and aluminates.

Proportioning and Mixing

If Portland cement is to be standardized so that it will have within certain ranges a definite chemical composition, so that it will be sound, set within certain time, and be of a strength that meets specific requirements, the pulverized materials must be most carefully analyzed and mixed only in correct propor-

tions. Variations in cement as manufactured in a given plant will generally fall within narrow limits, while those manufactured by different plants will show wider variations. These variations may be due to: (1) The percentage of gypsum or Plaster of Paris added as a retarder. (2) The contamination of the

FIG. 17. QUARRY ON KENTUCKY RIVER
General view of a section of the Ripy Brothers limestone quarry, High Bridge, Anderson County, Ky.

clinker by coal ash. (3) The absorption of carbon dioxide from the atmosphere. (4) The variations in the mixture of the raw materials.

Several attempts have been made to work out with mathematical precision formulas that will always yield a high grade product, when properly clinkered and ground. They have not all proved satisfactory. One formula given by Newberry was carbonate of lime $=$ silica $\times 5 +$ alumina $\times 2$. This formula represents the maximum of lime that a cement could carry, so that for actual practice the revised formula has been used which may be expressed as follows: Carbonate of lime $=$ silica $\times 4.8 +$ alumina $\times 1.9$.

When the proper proportions of the raw materials have been determined, they are carefully weighed out and thoroughly mixed. The mixture is passed successively through crushers, driers for removing moisture, another series of crushers which

reduces the mixture to a still finer state of subdivision, and finally through the pulverizers which reduce the mix to a powder so fine that 95 per cent of the material will pass through a 100 mesh sieve.

FIG. 18. OHIO RIVER CEMENT PLANT
Kosmos Portland Cement Plant, Kosmosdale, Jefferson County, Ky.

Burning the Mixture

Rotary kilns are used exclusively in the United States at the present time in the manufacture of Portland cement. The action of the kiln is continuous. In the kiln the cement mixture is burned to a clinker. The raw mix enters at one end of the kiln and passes out at the other as clinkers which should appear in the form of balls ranging in size from sand grains up to an inch in diameter. The clinker emerges from the kiln at a temperature of red heat and is cooled by water.

Rotary kilns are cylindrical in form, with a length ranging from 100 to 250 feet, and a diameter varying from 6 to 10 feet. They are built of steel plates lined with highly refratory material. They are supported in a slightly inclined position by friction rollers and are slowly rotated. In the migration of the raw mixture through the kiln, several different types of change takes place: (1) The loss of water so that the material is thoroughly dried. (2) The loss of organic matter that was present as an impurity in the materials used. (3) The loss of carbon dioxide of the limestone, cement rock, marl, etc. (4) The formation of the clinker through the chemical action of the lime, silica and alumina.

The time required for the cement mixture to pass through the kiln is from 1½ to 2 hours and the temperature reached is between 2,500 and 3,000 degrees. G. A. Rankin states in "Chemistry in Industry," Volume II, that the maximum temperature reached is about 1,425 degrees C., which equals 2,597 degrees F.

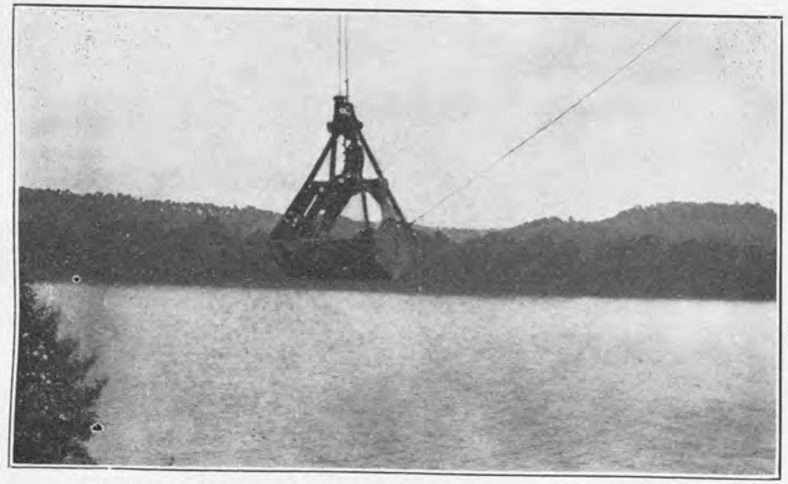


FIG. 19. MASS MATERIAL HANDLING, KOSMOSDALE
Electric crane for unloading barges of limestone for cement, Kosmosdale, Jefferson County, Ky.

Grinding the Clinker

After the cement clinker has been thoroughly cooled it is ground to a powder of remarkable fineness. There are two stages in the grinding process. In the first stage, the gyratory crusher is almost exclusively used in the United States. In the second stage, the ball and tube mills are in general use. According to F. W. Kelly, the degree of fineness required by specifications is such that 78 per cent of the product will pass through a sieve having 40,000 meshes per square inch. This sieve is finer than most silks and will hold water. In the final stage of grinding, gypsum not exceeding 3 per cent is added as a retarder in the setting time of the cement.

The finished cement is carefully sampled and tested to insure full compliance with specifications required. It is then stored in large bins until weighed out for shipment. The cement, when forwarded to the user is packed and weighed in pre-tied bags of special construction and is only touched by hand when placed in the freight car or truck or on a boat for shipment.

CHAPTER VI.

PROPERTIES OF CEMENT

According to H. A. Reid, the desirable properties in Portland cement are: (1) That when treated in the proposed manner it shall at the end of a definite period develop a certain strength. (2) That it shall contain no compounds which may at any future time cause it to change its form or volume, or lose any of its strength. (3) That it shall withstand any outside agency which may tend to decrease its strength or impair its durability.

Color

Variations in the color in Portland cement may be due to several different causes as: (1) Different types of rock or clay used in the process of manufacture of the cement. (2) To different temperatures attained during the process of burning the clinker.

Portland cement is usually of a dull gray color. Bluish gray indicates an excess of lime. Brown indicates an excess of clay in the mixture. Dark green indicates an excess of iron. Yellowish tints signify over-burning of the clinker.

Natural cement ranges in color from a light yellow through dark gray to a chocolate brown. Slag cements range in color from a bluish white to a lilac hue. There is sometimes in slag cement a bluish green tint due to the presence of calcium sulphide. Good slag cements will not stain blocks of white marble, or white Portland cement or a creamy white sandstone, and therefore such cements are often used in architecture.

Specific Gravity

The specific gravity of good Portland cement ranges from 3.10 to 3.25. Natural cement varies in specific gravity from 2.75 to 3.05. Slag cements vary fram 2.6 to 2.9.

A higher specific gravity than those given indicates an overburning of the clinker which is a source of weakness. A lower specific gravity may indicate an underburning of the product or the presence of adulterants. Plaster of Paris is in general use as

a legitimate adulterant. It serves as a retarder in the setting of the cement. The materials of lower specific gravity than Portland cement which are sometimes used in its adulteration are: (1) Natural cement. (2) Slag cement. (3) Unburned limestone. (4) Cinders. Furthermore, the age of cement, the fineness to which it is ground, and its composition may be responsible for a low specific gravity.

FIG. 20. AVAILABLE TENNESSEE RIVER LIMESTONE
Outcrop of limestone on the north side of the Tennessee River nearly opposite Birmingham, Ky.

Activity

By activity is meant the time required for a cement to set and harden. It may harden so quickly that the material is worthless for architectural or engineering purposes. It may set so slowly that it retards work and increases expense. The initial set takes place when the material begins to harden. The hard set occurs when the mass can not be appreciably distorted without rupture. The best cements acquire their initial set slowly and then harden rapidly, although it sometimes requires a year for a cement to attain its maximum strength.

G. A. Rankin in "Chemistry in Industry," Volume II, page 274, states "That the setting and hardening of Portland cement involves the formation of a gelatinous material which subsequently partially crystallizes; that the initial set is probably due to the hydration of tricalcium aluminate; that the hardness and cohesive strength at first are due to the cementing action of gelatinous material produced by the hydration of this aluminate, and of the tricalcium silicate; and that the gradual increase in strength is due to the futher hydration of these two compounds, together with the hydration of the dicalcic silicate.

FIG. 21. AVAILABLE LIMESTONE, LYON COUNTY, KY.
Outcrop of limestone on north side of Tennessee River, nearly opposite Birmingham, Kentucky.

Of the three compounds which thus take part in the setting and hardening of Portland cement, the tricalcic silicate is the best cementing constituent, that is, this compound is the only one of the three which, when mixed with water will set and harden within a reasonable time to form a mass which in hardness and strength is comparable to Portland cement."

Soundness

A good cement will not expand, contract or check after the initial set has begun. Unsoundness in cement is often due to an excess of either free or loosely combined lime. The presence of

the excess of lime may be due to any one or more of several factors. (1) To incorrect proportioning. (2) To insufficient grinding of the raw materials. (3) To underburning the products in the kiln. (4) To insufficient grinding of the calcined rock. (5) To lack of seasoning the finished product. Fresh cement made of good material will sometimes set unsound, while the unsoundness may disappear in a few weeks time.

Expansion and disintegration may be caused: (1) By an excess of magnesia. (2) By an excess of alkalies. (3) By the presence of sulphides. Contraction may be caused by an excess of clay. In slag cements the unsoundness is generally due to the presence of quicklime or an excess of magnesia, or the presence of sulphides.

Fineness

The finer a cement is ground, the better will be its quality and the greater will be its covering capacity. It is often stated that for Portland cement, 92 per cent of its weight should pass through a 100 mesh sieve. For natural cement, 90 per cent must pass a 100 mesh sieve. For slag cement, 97 per cent must pass a 100 mesh sieve.

F. W. Kelley, President of the Portland Cement Association, states that the cooled clinker when ground to the fineness required by the standard specifications, must have 78 per cent of the product pass through a sieve having 40,000 meshes per square inch.

Tensile Strength

The tensile strength of cement is easily determined and is generally considered a true measure of the compressive, transverse, adhesive and searing values. H. A. Ried in his book on Concrete and Reinforced Concrete Construction, gives the tensile strength for Portland cement 28 days of age (one day in moist air and 27 days in water) as 600 pounds. Natural cement of the same age and under the same conditions, he gives as 225 pounds. Slag cement under the same conditions he gives as 500 pounds.

Compressive Strength

The Watertown Arsenal Report of 1902 gives the compressive strength of Portland cement gauged with 25 per cent water at the age of one day in air as 430 pounds per square inch. At

28 days of age in air as 3,130 pounds. At 28 days of age, one in air and 27 in water, as 7,580 pounds.

Chemical Composition

The chemical composition of Portland cement is one of the most important guides to the quality of the product. The chemist usually grinds the cement to a very fine powder before determining any constituent that may be present. It is advised by some engineers that the true nature of the cement is best determined without pulverizing the material or otherwise changing its physical characteristics. In this manner the free silica which is always inert is separated from the mixture and determined separately. The combined silica is an active agent in the setting of the cement.

G. A. Rankin in his article on Portland Cement in Chemistry and Industry, Volume II, page 271, states "That the chemical constitutents of Portland cement are largely compounds of lime, alumina, and silica, of which tricalcic silicate, 3 CaO, SiO_2, dicalcic silicate, 2 CaO, SiO_2, and tricalcic aluminate, 3 CaO, Al_2O_3, are the major constituents, and uncombined lime, CaO, and the compound 5 CaO, $3Al_2O_3$ are minor constituents. The compounds formed by the oxides of iron, magnesium, and the alkalies, which are always present in cement in small percentages, are a matter of some uncertainty. It would appear, however, that the iron oxide is present to some extent, as dicalcic ferrite, 2CaO, Fe_2O_3, and that the alkalies and magnesia are largely present as glass."

The average composition of eleven well-known American cements is given here for reference.

Silica, SiO_2	21.90 per cent
Alumina, Al_2O_3	7.89 per cent
Ferric Oxide, Fe_2O_3	3.09 per cent
Lime, CaO	62.04 per cent
Magnesia, MgO	2.33 per cent

The following shows the average composition of seven high class American cements with the soluable silica separated in the analysis from the insoluble silica.

Silica, SiO_2 (soluble)	18.45 per cent
Silica SiO_2 (insoluble in 10 per cent. HCl)	4.38 per cent
Alumina and iron oxides	9.46 per cent
Lime, CaO	61.89 per cent
Magnesia, MgO	1.78 per cent
Sulphur trioxide, SO_3	1.87 per cent
	97.83 per cent

CHAPTER VII.

CONCRETE

This terse chapter on concrete is here introduced to show the large application of Portland cement to American industries. Concrete is composed of Portland cement, water, fine and coarse aggregate. The components are mixed in definite proportions and of consistency specified. It is sometimes found necessary to vary the proportions of the fine and coarse aggregate in order to make the required concrete of maximum density, but the pro- proportion of cement per cubic yard of mixed concrete remains unchanged.

Standard Mixes

1. One part of Portland cement, two parts of fine aggregate, four parts of coarse aggregate.
2. One part of Portland cement, two and one-half parts of fine aggregate, five parts of coarse aggregate.
3. One part of Portland cement, three parts of fine aggregate, six parts of coarse aggregate.
4. One part of Portland cement, two parts of fine aggregate, three parts of coarse aggregate.
5. One part of Portland cement, four parts of fine aggregate, eight parts of coarse aggregate.
6. One part of Portland cement, two parts of fine aggregate, three and one-half parts of coarse aggregate.

The above aggregates are inert. Concrete hardens because of the reactions between Portland cement and water. The strength of concrete is affected: (1) By the quantity of cement used. (2) By the volume of water used. The controlling factor in the strength of concrete appears to be the ratio between the volume of Portland cement used and the volume of water used in the concrete mix. The ratio between these two factors which may be expressed by the formula $\frac{W}{C}$ can be reduced in three ways:

1. By reducing the quantity of mixing water.
2. By improving the grading of the aggregate.
3. By using more cement, that is, using a richer mix.

The volume of water used should always be as small as will give the consistency required for the work at hand. If too small a quantity of water is added so that the mixture is too dry to work, there is a decrease in the strength of the concrete. This condition may be overcome by the use of more cement. A thorough mixing increases the strength of concrete.

Theory of Concrete

The proportions of the concrete should be so adjusted that all the voids in the sand will be filled with cement paste, and all the voids in the gravel or broken stone will be filled with cement mortar. The cement is the most expensive constituent. If more cement or mortar is used than is required to fill all the voids, the cost is needlessly great. In a perfect concrete, every grain of sand will be coated with a cement paste, and every point of each fragment of broken stone or gravel will be covered with cement mortar.

Gravel vs. Broken-Stone Concrete

At the same price per unit of volume, broken stone is better for the following reasons: (1) The cement adheres more closely to the rough surfaces of the angular fragments of the broken stone than to the smooth surface of the rounded pebbles. (2) The resistance of the concrete to crushing is due in part to the frictional resistance of one piece of aggregate to moving on another. Therefore, broken stone makes a stronger concrete than gravel.

Advantages of Concrete

Because of the rapidly increasing demand for Portland cement in the construction of permanent highways throughout the United States, the advantages of concrete for a pavement foundation are here given: (1) It gives a smooth, uniform surface upon which to lay the pavement. (2) It prevents the surface water from percolating to the subgrade. (3) By its thickness and resistance to flexure, it distributes the concentrated load over a considerable area of the subgrade. (4) Concrete acts as a bridge to support the pavement in case of a settling of the subgrade. (5) Being impervious to water and a non-conductor of heat, concrete protects water and gas pipes from freezing.

CHAPTER VIII.

MATERIALS IN KENTUCKY

Limestones low in magnesia and silica and otherwise satisfactory as cement materials are widely distributed in Kentucky, and range in age from the Ordovician to the Pennsylvanian. It does not follow, however, that all of the seventy or more geologic formations within the state are suitable for the manufacture of Portland cement.

It does not seem advisable to the author to even list all the formations, but rather to call particular attention to the most important terranes for possible use in the cement industry.

The state naturally divides itself into five distinct districts for investigation and description of its possible cement materials. These may be listed as follows: (1) Eastern Kentucky, including the Knobs. (2) Central Kentucky, or the Bluegrass section. (3) The Mississippian Plateau, or Central, Southern and Western Kentucky. (4) The Western Coal Fields. (5) The Jackson Purchase. In the description of the cement possibilities of the state, this order will be followed.

An entire chapter might be written upon each district, but it does not seem advisable to describe more than the most important fields.

Eastern Kentucky

The area embraced in Eastern Kentucky, includes all the eastern part of the State and the Knobs adjacent to the region. Many of these Knobs border the Bluegrass section on the east. The western boundary may be marked by a line drawn aproximately north 45 degrees east through Clinton, Wayne, Pulaski, Rockcastle, Estill, Powell, Menifee, Rowan and Lewis Counties. The last county mentioned borders the Ohio River. The area contains thirty-six counties, or nearly one-third the total number of counties within the state.

The rocks are essentially Mississippian and Pennsylvanian in age. Some of the Mississippian limestones, like those in Carter County, are well suited for cement material. A number of

limestone beds occur interbedded with the shales and sandstones of Pennsylvanian age. These limestones are usually low in magnesium carbonate content and not particularly high in calcium carbonate content. The calcium carbonate usually ranges from 85 per cent to 95 per cent. The Pennsylvanian limestones are usually thin bedded and therefore not comparable in value to the purer and thick bedded Mississippian limestones. They are also often covered with beds of shale and sandstone which would increase the cost of the manufacture of Portland cement from them.

Ashland

All things being considered, the most favorable location for a cement plant in Eastern Kentucky is in Ashland. However, the essential materials of the cement mixture would have to be hauled some distance unless the limestones were mined.

Limestones

Limestones occur in the Olive Hill district that are remarkably low in their magnesium carbonate content. An analysis of one sample collected at Olive Hill gave only 0.67 per cent magnesium carbonate and another gave 1.60 per cent magnesium carbonate. The supply of this limestone is ample for a Portland cement plant. Freight rates should be secured that would make the cost of purchase and transportation of this limestone to Ashland financially attractive.

The Mississippian limestones of the Olive Hill district should pass under the Pennsylvanian formations of Boyd County and in the vicinity of Ashland should be reached at a depth of less than 450 feet. Records of well logs give this depth for Ashland as 420 feet. It is reported upon good authority that these limestones are reached near Ironton, Ohio, at a depth of practically 500 feet, and that a shaft has been sunk to this depth, the stone mined and used in the manufacture of Portland cement, at Ironton. If the limestone can be mined at the greater depth at Ironton and used with profit in the cement industry, it should be possible to mine it also at Ashland.

Clays

Northwest of Ashland, alluvial clays border the Ohio River. They occur between the Ashland-Greenup Pike and the Ohio River. Surface indications suggest that these clays occur in

sufficient quantity for the manufacture of Portland cement. It would be necessary to know that the ratio of the alumina and iron oxides to the silica is correct: viz. 1:2.5-3, before attempting to use them in the cement industry.

About one mile west of Coalton and directly west of the Brickley cut on the Chesapeake and Ohio Railroad, there occurs about 50 acres of good clay that ranges from four to six feet in

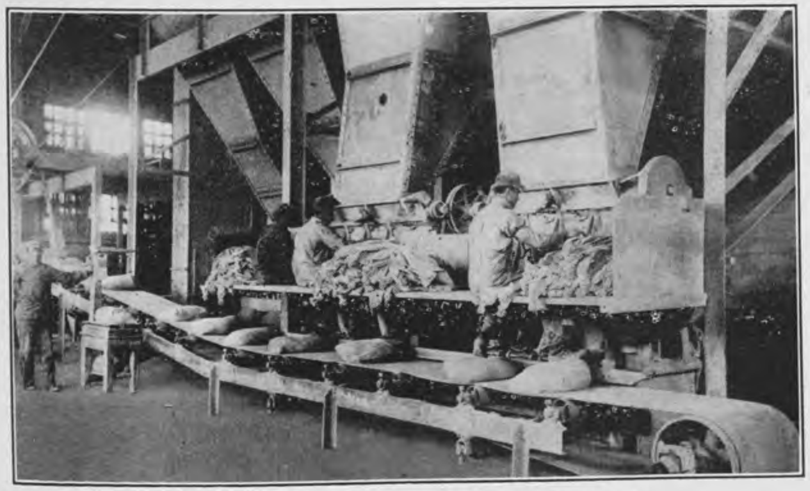


FIG. 22. BAGGING IN A CEMENT MILL
An automatic bagging machine for sacking finished Portland cement. On these machines one operator can fill as many as 500 bags an hour.

thickness. This clay is reasonably free from sand and gravel and over a considerable portion of this acreage there is no surface soil to remove. This clay should be a possible Portland cement material, provided the ratio of the iron and alumina to the silica is correct for cement mixtures. These clays should be carefully tested out with a soil auger to ascertain the approximate tonnage and the samples collected at various points carefully analyzed. This clay could be hauled by the Chesapeake and Ohio Railroad to Ashland with freight rates that would be attractive.

The advantages of establishing a cement plant at Coalton would be:

(1) The close proximity to one of the essential constituents for the manufacture of Portland cement, viz., the clay.

(2) The short haulage with low freight rates of the second constituent necessary in the manufacture of Portland cement, viz., the limestone.

As already noted, this material occurs in the Olive Hill district in adequate tonnage and with a remarkably low magnesium carbonate content.

(3) The close proximity of the Chesapeake and Ohio Railroad for the shipment of the finished product.
(4) An ample supply of water on the property for all manufacturing purposes.
(5) The presence of only one plant manufacturing Portland cement within the state.
(6) An ever-increasing demand for Portland cement in the erection of fire-proof buildings and the construction and maintenance of permanent roads.

Possibly the most practical problem in the cement industry for consideration by Ashland capitalists is the manufacture of Pozzuolanic cement which is often called slag cement. It is sometimes classified as Portland cement, but it differs materially from Portland cement as elsewhere shown in this report. Slags are ample in Ashland for this new industry.

Morehead

As the question has arisen concerning the advisability of a cement plant at Morehead, the following results of an investigation of this particular field are here given.

The clays around Clearfield, up Dry Run, Morgan Creek, the Licking River and around Frenchburg, appear to be too sandy for use as cement material. However, there does occur on Clack Mountain fifty to sixty feet of limestone that is suitable for the manufacture of Portland cement. A part of this limestone is flinty and breaks with a conchoidal fracture like the Tyrone limestone. A part of this limestone is well crystallized and susceptible of a good polish.

Associated with these limestones, are beds of green and red clay of unknown thickness because not yet opened up for inspection. Upon the opposite side of Clack Mountain the beds of clay were twenty-four feet in thickness. The area has been trenched to some extent to ascertain its character and tonnage. Much of

this clay is associated with gravel which would render the product too siliceous for cement manufacture. The chemical analysis of the lower beds in the limestone and the green clay or shale shows these formations are suitable for use together in the manufacture of Portland cement. This locality is not most favorably situated for a successful Portland cement industry.

Stanton

It has been suggested that a Portland cement plant could be established with profit at Stanton, Powell County. On property owned by Mrs. Kate S. Bohanan, daughter of J. C. Patrick, of Stanton, there occurs what appears to be the best cement material in this vicinity. The St. Louis limestone covers 250 acres more or less to a thickness of 150 feet, a vertical working face several hundred feet in length can easily be secured.

On the flood plain between the limestone cliffs and the Red River, there are approximately 150 acres covered with clay. From a series of test holes with soil auger, this clay deposit was found to vary from 16 to 21 feet in thickness, with an average thickness of approximately 18 feet. An analysis of this clay, which analysis the author of this report has not seen, is said to show the correct ratio of the silica to the alumina and iron oxide for use in the cement industry.

The apparent advantages of this site for a cement plant appear as follows:

1. A practically inexhaustible supply of the St. Louis limestone directly upon the property.
2. A sufficiently large tonnage of clay upon the property to last the mill for many years.
3. Coal for fuel only seven or eight miles up the Red River.
4. Oil for fuel some fifteen miles distant in Lee County.
5. Oil refining plant at Compton Junction.
6. Gas of unknown quantity upon the property.
7. Red River only one-half mile to the east to furnish water for all purposes.
8. Easy shipment of the finished product by barges through the Red River, Kentucky River, Ohio and Mississippi Rivers.

The plan contemplated by the owners of the property is a plant that will give an output of 1,500 barrels of Portland cement per day for the first year, and 3,000 barrels of cement

per day thereafter. The supply of materials for the cement mixture is ample, provided the limestone and the clay meet the required ratios for good cement.

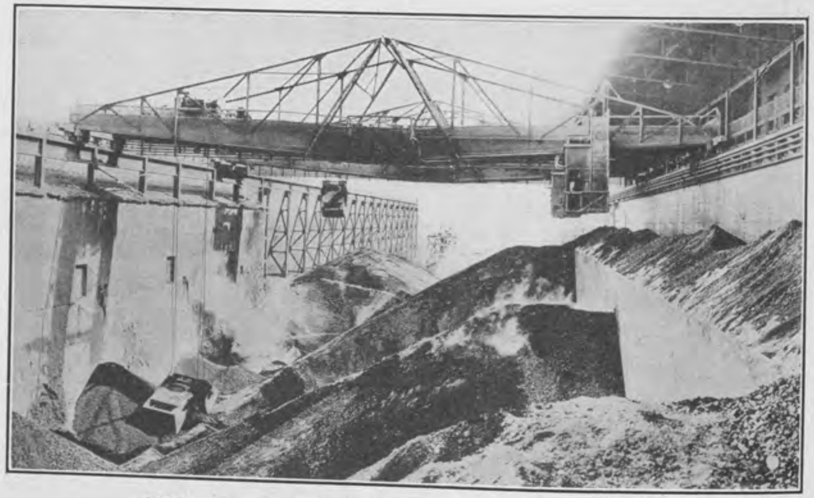


FIG. 23. CEMENT MATERIALS IN PROCESS
A clinker storage in a Portland cement plant. After the clinker leaves the rotary kiln it may be stored in the open without deterioration.

Central Kentucky

The Bluegrass section of North Central Kentucky embraces more counties than any other distinct geographic province of the State. There are thirty-nine counties in the district which lacks only one county of representing one-third of the total number of counties in Kentucky. This division not only includes the counties affected by the Cincinnati Arch in its southern extension into Kentucky, but also the Knob counties adjacent on the south and southwest. The Knob counties on the east were covered under the caption of Eastern Kentucky.

The terranes of the Bluegrass region or of the north central Kentucky are predominantly Ordovician in age with the Cincinnatian series far in excess of the Champlanian. The Silurian, Devonian and Mississippian series are represented in the Knob counties.

Champlainian

The limestones of the Champlanian series occupy much of the counties of Bourbon, Fayette, Franklin, Scott and Woodford, and smaller portions of Anderson, Boyle, Clark, Henry, Mercer, and Owen counties. The formations involved represent a combined thickness of some 700 feet of solid, chiefly non-magnesian, limestone. The base of the series represented by the Camp Nelson formation is sometimes a little too high in its magnesium carbonate content for good cement. Microscopic slides

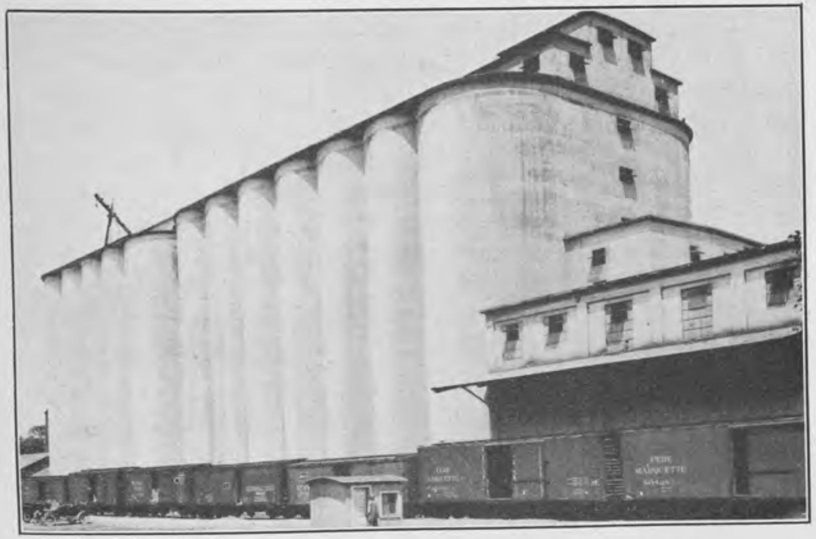


FIG. 24. TEMPORARY STORAGE FOR CEMENT
Concrete storage bins at a Portland cement plant provide a means of storing the finished Portland cement. From these bins the material is carried to bagging machines and sacked ready to be shipped.

of this formation have shown the rock in the upper portion to be well dolomitized. The Oregon bed which overlies the Camp Nelson is a dolomite and therefore unsuited for the manufacture of Portland Cement. These two formations are confined to the lower portions of the rocks exposed in ravines and their adjacent areas in central Kentucky. The overlying limestones reaching approximately 500 feet in thickness, usually range from 90 to 95 per cent in their calcium carbonate content. As far as chemical composition is concerned, it would appear that central Kentucky has an inexhaustible supply of non-magnesian limestone for the cement industry.

The most conspicuous formation in this series is the Tyrone limestone which overlies the Oregon formation. It is a very

massive, compact, thick-bedded non-magnesian, white to dove colored building stone, well suited for use in the Portland cement industry. It breaks with a conchoidal fracture and trims easily into ashlar blocks. The Stone shows on its fractured surfaces facets of calcite, which have given to the rock the name "birdseye limestone." The perfect cleavage of these rhombs of calcite sparkle by reflected light like the eyes of a bird.

The author has constantly found the name Kentucky marble applied to this formation. It is not entirely a misnomer, for in petrographic study this rock is proven to be a semi-crystalline, non-dolomitic limestone or marble. This stone can be seen in the walls of the Old State House at Frankfort, and in many other structures, also. Its characteristics are so pronounced that the formation can be easily recognized by any careful observer. Probably this formation contains a larger tonnage of limestone well suited for the manufacture of Portland cement than any other formation within the state.

The Lexington limestone outcrop forms two main areas in north central Kentucky. One lies in the Kentucky River drainage area, and the other in the south fork of the Licking River drainage. The two areas combined constitute the well-known Inner Bluegrass Region. The combined thickness of the Lexington formations is approximately 250 feet. It lies over the Tyrone limestone from which it is separated by a disconformity. The Lexington limestone is a grayish, granular, crystalline limestone which also bears a strong contrast in texture in passing from on formation into the other. The Tyrone is fine grained and compact, while the Lexington is medium to coarse grained and often well crystallized.

Cincinnatian Series

The rocks of the Cincinnatian series are thinner bedded and far more shaly than those of the Champlanian series. They occupy most of the north central portion of the State. They consist largely of dark blue, semi-crystalline, argillaceous, thin bedded limestones, with many interbedded shale layers. These limestones are generally satisfactory for the manufacture of Portland cement. This holds especially true of many outcrops of the Cynthiana limestone in the central portion of the district and of the Fairmount and Bellevue limestones around Newport

and Covington. The Fairmount limestone may reach forty feet in thickness and the Bellevue limestone twenty feet in thickness. The Cynthiana limestone varies from forty to ninety feet in thickness.

PHOTOGRAPH BY W. R. JILLSON

FIG. 25. CEMENT HOUSES NEAR KOSMOSDALE

These dwellings were erected by the Kosmosdale Portland Cement Co. for their employees and have given good satisfaction.

Kosmosdale

With the large areas of non-dolomitic and non-siliceous limestones in Kentucky, it may seem a little strange to some readers that only one cement plant has as yet been established within the State. This plant is located at Kosmosdale, some twenty miles southwest of Lousiville. The plant is situated on the Dixie Highway, on the Illinois Central Railroad and on the Ohio River. The location is ideal for the shipment of the finished product. The limestone is obtained from the cliffs some thirty miles west of Kosmosdale and brought to the plant by barges on the Ohio River. The clay is alluvial and is obtained from the ancient flood plain directly back of the mill. The supply is ample. That the mixture of this limestone and clay makes a correct Portland cement mix for burning is proved in the high grade of Kosmos Portland cement. The plant has a capacity of 1,200,000 barrels of cement per annum.

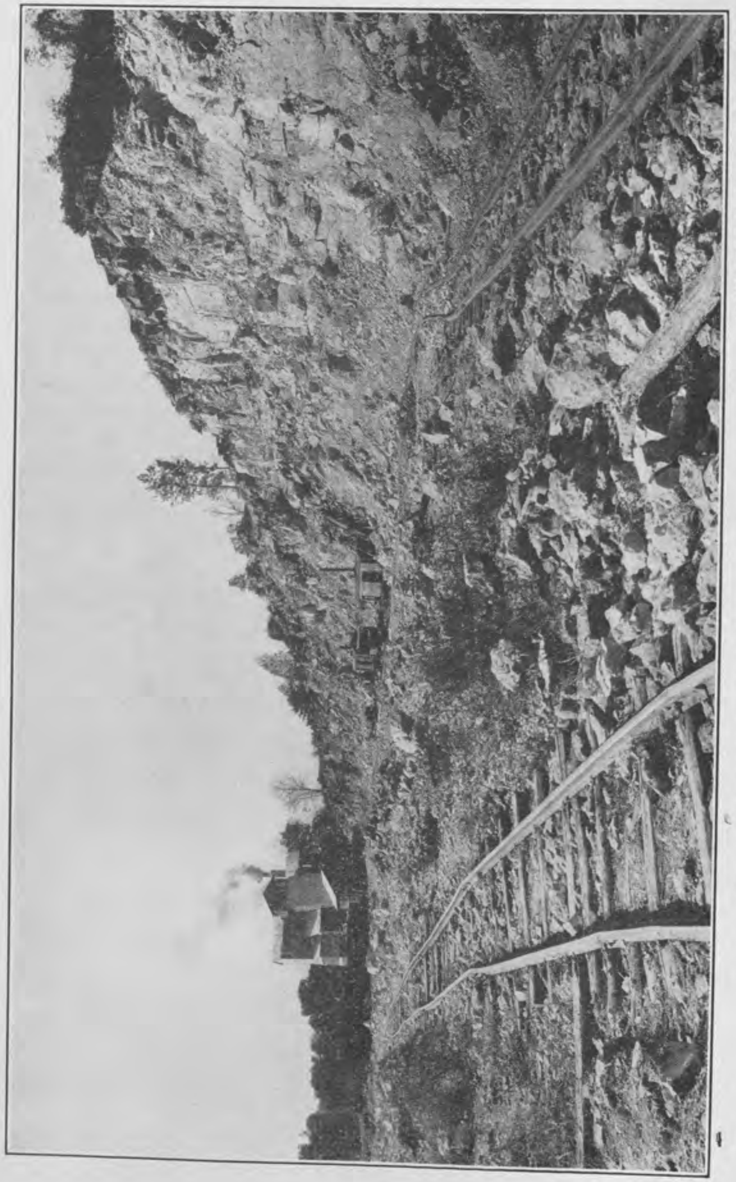


FIG 26. OLIVE HILL LIMESTONE CO., J. H. MOBLEY
"35,000 tons per day."

PHOTOGRAPH BY W. R. JILLSON

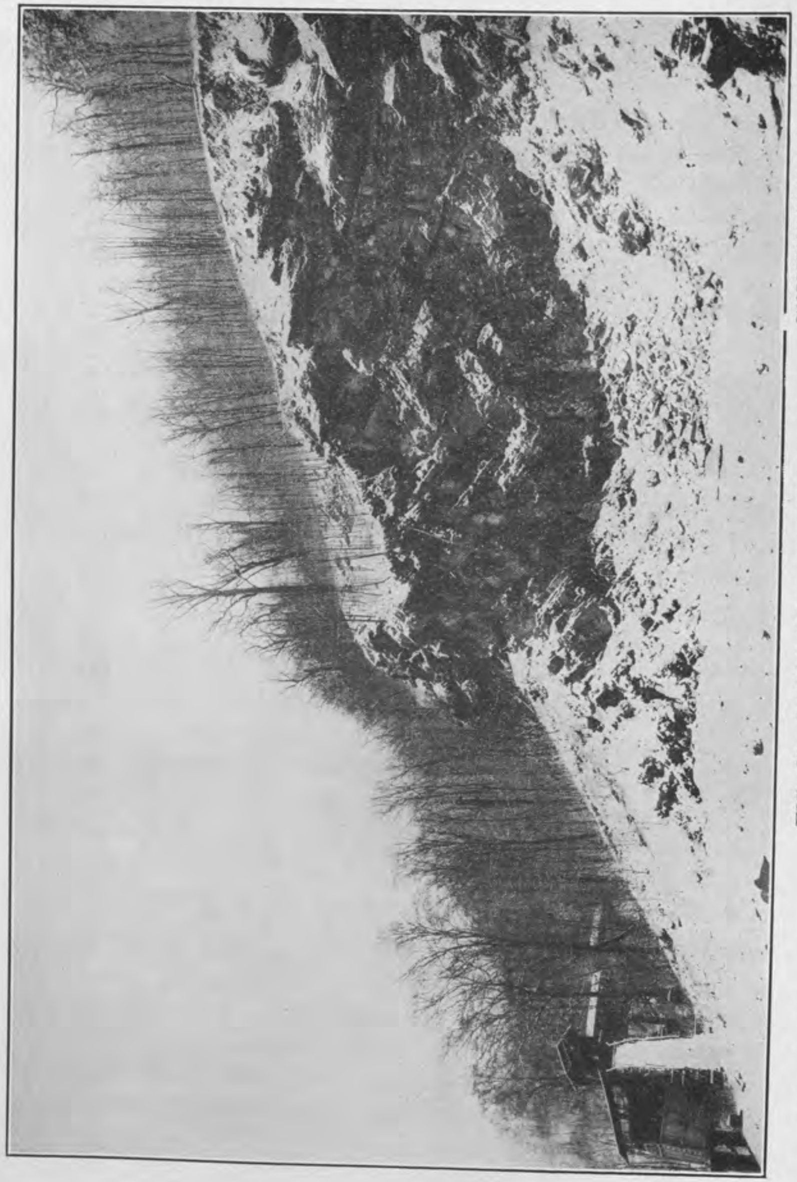
High Bridge

There has been considerable discussion concerning the establishment of a Portland cement plant at High Bridge. This location is directly on the line of the Southern Railway System, twenty-one miles south of Lexington. The American Stone and Ballast Company, with headquarters at High Bridge and Lawrenceburg, own and operate one of the largest stone quarries within the state. The quarry is situated at High Bridge, and was opened up about thirty years ago. The length of the working face of this quarry is from 1,500 to 2,000 feet. The height is from 60 to 63 feet with an opening on the quarry floor 17 feet deep. This makes a total working face of 80 feet. Eight to ten acres of stone have already been quarried to the depth of 60 feet, but the supply is inexhaustible. It is proposed, if a plant should be installed here, to use largely the Tyrone limestone. The lower portions of the quarry richer in magnesium carbonate could still be used as crushed stone for road work, or the more massive beds could be used as marble for both constructional and decorative interior work.

It has been suggested that the clay for the proposed industry be obtained from a shale bed, situated ten miles south of Danville. This shale is of steel gray color, sixty feet in thickness and close to the railroad. A switch of some 100 rods would be required to reach the maximum thickness of the shale. Shale, also, occurs at Junction City, two miles south of Danville. These shales are said to carry the correct proportions of silica and alumina for the manufacture of Portland cement. Test samples of cement have been made from Tyrone limestone and Junction City clay and found satisfactory. A chemical analysis of at least one of these cements will appear in the chapter on Analyses.

Covington-Newport

There has been a suggestion made from time to time that there was ample room in Kentucky for the establishment of a cement plant at Covington, or Newport, or even Ludlow. The advantages in the shipment of the finished product may have been a large factor in determining such a suggestion. With Cincinnati as a railroad center to the north, and with water route by the Ohio River, the advantages are obvious.



PHOTOGRAPH BY W. R. JILLSON

FIG. 27. LARGE BELL COUNTY QUARRY

The T. J. Asher limestone quarry and crusher adjoining the L. & N. Station, Pineville, Ky. The limestone is Mississippian brought up by the Pine Mountain fault.

The advantages for the natural limestone and clays or shales for the cement mixture are not quite so apparent. Limestones do occur at Mentor, some twelve miles to the southeast of Newport, in a rather narrow belt, as far as exposures are concerned, along the Ohio River. At Ludlow, a few miles to the west of Covington, the same limestone, Maysville, which over-

FIG. 28. REINFORCED CONCRETE ARCH
Louisville-Bardstown Road, Jefferson County.

lies the Eden shales, is at least one hundred feet in thickness. The magnesium carbonate content of this limestone is usually less than two per cent. However, these limestones are more siliceous than the Tyrone, and are not regarded by the author as equal in value to the Tyrone as cement material.

The shales along the Ohio River in Compbell and Kenton Counties, would need careful chemical analyses to prove the correct ratio of the silica to the alumina and iron oxides.

Mississippian Plateau

The Mississippian Plateau, which embraces parts of central, southern and western Kentucky, includes the Mississippian formations that lie beneath the Bluegrass region of north central Kentucky on the east, and the Pennsylvanian coal measures on the west. The counties of Grayson and Edmonson, which are about equally represented by the Mississippian and Pennsylvanian terranes, are here included because they are not distinctively in the western coal measures. The Plateau includes the counties that lie between the western coal measures on the north, and the

Tennessee boundary on the south, and also those counties which lie between the western coal measures on the northeast and the Jackson Purchase on the southwest. Twenty-seven counties naturally belong in the Mississippian Plateau region.

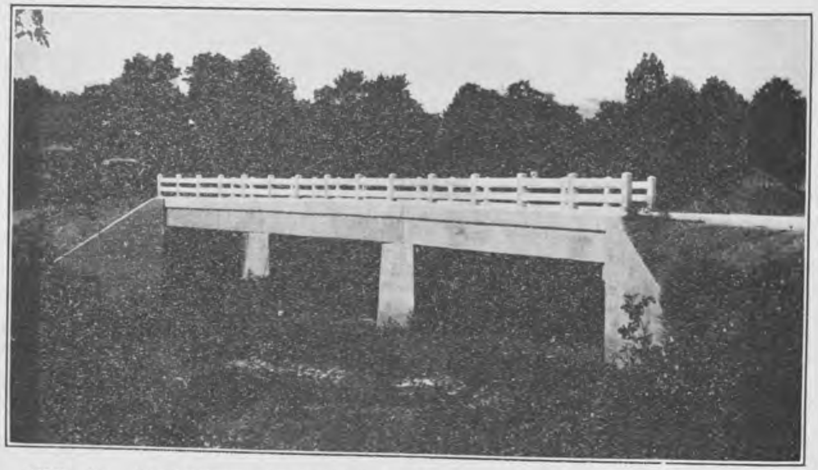


FIG. 29. CONCRETE-CEMENT BRIDGE, WHITLEY COUNTY, KY.

The terranes of the Mississippian Plauteau are predominantly Mississippian in age. However, a little Ordovician, Silurian, Devonian and Pennsylvanian are included with the Mississippian.

Most of the Mississippian limestones are low in their magnesium carbonate content, and therefore well suited for use in the manufacture of Portland cement. The lower part of the Mississippian series carries some beds of cherty limestone that are too siliceous to serve as a saitsfactory Portland cement component.

The Mississippian system contains two oolitic limestones that are regarded as especially promising limestones for use in the manufacture of Portland cement. The lower of these formations is in the Warsaw stage and is definitely recognized as the Spergen limestone. Its thickness varies from twenty to twenty-five feet. It forms a rather broad belt of pronouncedly oolitic rocks that outcrop in Barren, Christian, Hardin, Larue, Meade, Warren, Todd, and Trigg Counties. This formation is overlaid by the St. Louis limestone which is often too high in its magnesium carbonate content and too rich in free silica, for use in the manufacture of Portland cement.

The Mammouth Cave series contains the St. Genevieve formation which overlies the St. Louis limestone. The St. Genevieve rocks attain a thickness of 290 feet. The St. Genevieve limestone is pronouncedly cavernous and non-magnesian. It outcrops in Caldwell, Christian, Crittenden, and Livingston counties. It is regarded as excellent Portland cement material.

Bowling Green

The most favorable location for a Portland cement plant in this physiographic division of Kentucky, appears to be at or in the neighborhood of Bowling Green, for in Warren County there is an inexhaustible supply of one of the essential components of Portland cement mixtures, viz., the limestone. There are twenty-two limestone quarries in this county, most of which are in the Spergen oolitic limestone which is locally known as the Bowling Green stone. It is the Spergen limestone of Prof. A. M. Miller of the University of Kentucky.

In color, the Spergen oolitic limestone is white, very light gray, gray and sometimes dark gray. In texture, the stone is from fine to medium grained. The fracture sometimes crosses the oolites and sometimes it goes around them, so that the oolites stand out conspiciously on the broken surface. Most of the oolites are round, but some of them are enlongated. The stone has perfect rift and grain, is easily worked into rectangular blocks and would be easily crushed and pulverized in a cement mill.

The second essential component of the cement mixture, viz.: the clay or shale, would have to be brought in from outside the county. This would be a disadvantage.

The advantages of this cite for the location of a mill may be listed as follows:

1. An inexhaustible supply of non-magnesian, non-siliceous limestone.
2. River waters for all manufacturing purposes.
3. Transportation of raw materials to the plant by barges from a large number of possible quarries.
4. Close proximity to coal supplies as a source of fuel.
5. Close proximity to oil as a possible fuel.

FIG 30. CEMENT IN DAM CONSTRUCTION

While the Dix River Dam near Burgin is of the type commonly known as rock filled there is evidence as shown above of the use of much cement and concrete in its construction.

6. Easy shipment by water route of the finished products.
7. Easy shipment by rail of the finished products.

The Western Coal Field

The Western Coal Field embraces a smaller number of counties than any other geographic province of the State, save the Jackson Purchase. The area is situated in the western part of Kentucky and lies between the Ohio River on the north and the Mississippian terranes on the south. The terranes are about equally divided between the Mississippian and the Pennsylvanian systems.

The limestones of this district which are largely interbedded with shales and sandstone, are usually not as free from magnesium carbonate as the Spergen oolite and the St. Genevieve oolite, yet the magnesium carbonate content falls below 4.5 per cent. The calcium carbonate falls between 80 and 90 per cent, while the Spergen oolite in Warren County is practically pure calcium carbonate. As a rule, the limestones are thin bedded and therefore more expensive to work than the limestones of Warren county. In the northern part of the Province there is an abundance of alluvial clay that might be utilized. At Owensboro in Daviess County, the Owensboro Clay Products Company manufacture face brick from a clay deposit located 200 feet from the Ohio River and one-half mile west of Owensboro. There is fifty feet of clay above the track on the floor of the pit and thirty feet of excellent shale of uniform texture on the floor beneath the track, but the actual depth is unknown. Eighty feet of clay and shale is definitely proven. This clay and shale deposit looks very promising as possible Portland cement material. Between one and two miles from Owensboro on the road to Henderson and St. Louis Railroads, there is a large tonnage of drab-colored, highly plastic clay which appears promising as a clay for the manufacture of Portland cement.

At Maceo, also in Daviess County, on the farm of R. M. Robinson of Maceo, there are twenty acres of high grade, dark-bluish gray, highly plastic alluvial clay. This property is within 100 yards of the Louisville, Henderson and St. Louis Railroad. There is practically no overburden to remove. This clay formation is at least eighteen feet in thickness, but the actual depth is not known. This clay is reported to have the cor-

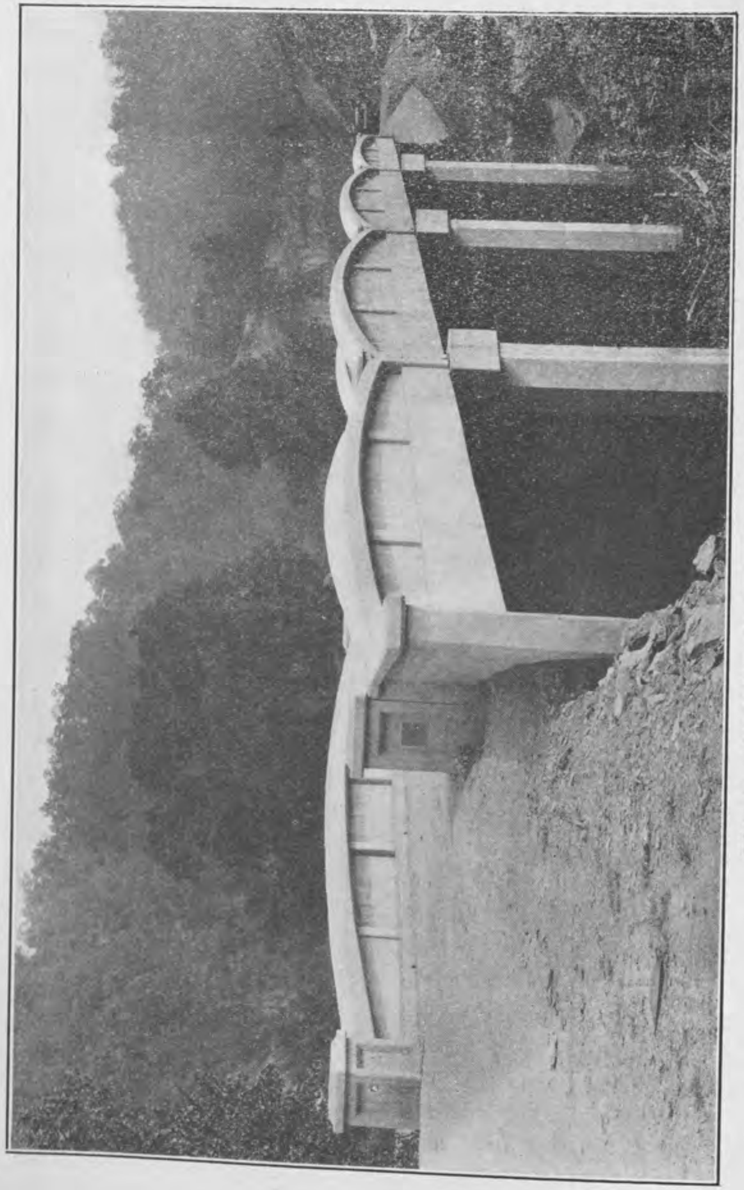


FIG. 31. CEMENT IN BRIDGE CONSTRUCTION

The view shows newly completed cement bridge over the North Fork of the Kentucky River in Perry County, above Hazard on State road project 4-BB2, district number 5. This photograph was taken in 1925.

rect ratio of silica to the alumina and iron oxide for cement mixture.

In Henderson County, there are floodplain clays bordering the Ohio River along the northern portion of the county. These clay deposits appear in several localities and if found in sufficient quantity might be used in the manufacture of Portland cement, provided correct ratios can be established.

Henderson

The most favorable locality in the Western Coal Field for establishment of a Portland cement plant is at Henderson. The limestone can be secured from the Webster Stone Company of Irvington. W. J. Piggott owns and operates a quarry one and one-half miles northwest of Irvington. A spur of the Louisville, Henderson and St. Louis Railroad extends from the main line to the quarry. The quarry is approximately 250 feet in length with a vertical working face of sixty feet. The stone has been used for concrete and shipped to Cincinnati, St. Louis and Nashville. It is nonmagnesian and an excellent stone for use in the manufacture of Portland cement. Good freight rates should be secured for shipping the stone to Henderson over the Louisville, Henderson and St. Louis Railroad.

The advantages of locating a Portland cement plant at Henderson may be listed as follows:

1. Its close proximity to the Ohio River which favors low transportation rates to open markets.
2. Henderson has three railroads which aid in shipping the cement to various points by rail.
3. Its close proximity to Evansville, Indiana, which is a good railroad center with seven railroads.

The Jackson Purchase

The Jackson Purchase embraces a smaller number of counties than any other geographic Province of the state. It is situated in the extreme southwestern corner of Kentucky. Three of its boundary lines are navigable rivers. Its boundary lines are, on the north, the Ohio River, on the east, the Tennessee River, on the south, the State of Tennessee, on the west, the Mississippi River. The terranes are largely unconsolidated sediments that belong to the Cretaceous and Quarternary

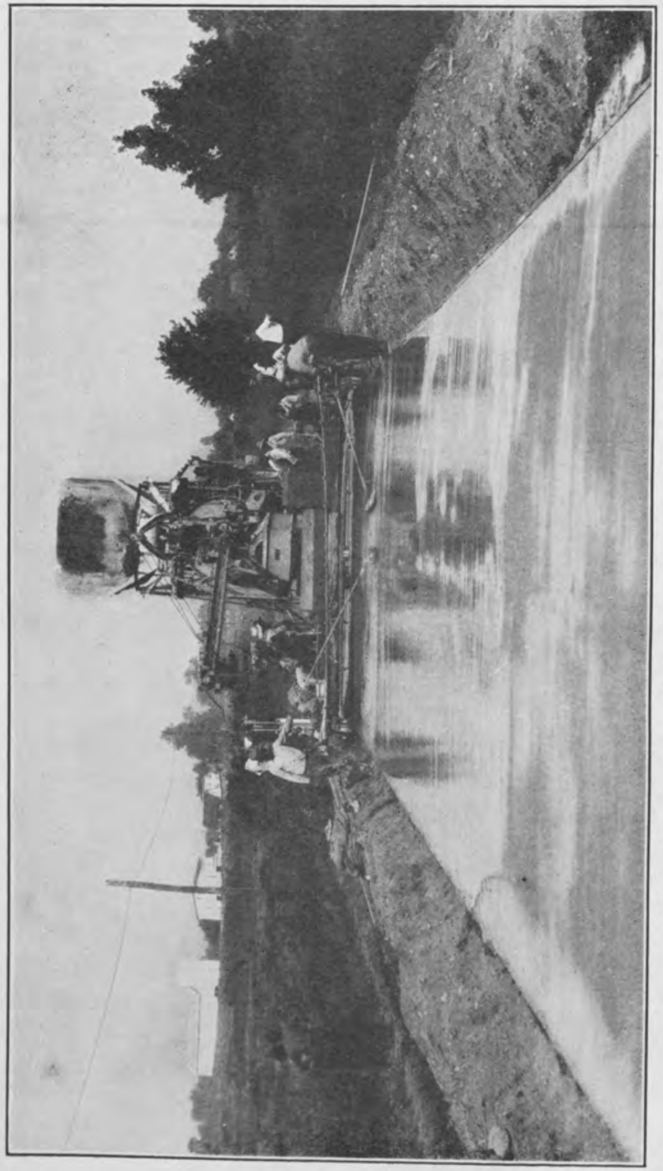


FIG. 32. LAYING A CEMENT SURFACED ROAD

The view shows the newly constructed concrete-cement Stanley road at a point about 8 miles east of Owensboro.

systems. In general, where the Mississippian limestone outcrops in the eastern part of the Purchase, the altitudes are low and the region swampy.

Paducah

It has often been suggested that a Portland cement plant might be established at Paducah. If this were done, then the essential components of the cement mixture would have to be brought into Paducah or its immediate environs.

Limestone apparently suitable for the manufacture of Portland cement occurs in ample supply on the north shore of the Tennessee River at Mile Post, No. 21. The working face of the quarry could easily be one-quarter of a mile in length and the altitude of the face sixty feet. Chemical analysis of this stone shows from 98 to 99 per cent calcium carbonate and therefore the material is very low in magnesium carbonate and silica content. It may be listed as an ideal Portland cement limestone. The quarry from which the samples for analysis came is situated thirty-one miles above Paducah and opposite Birmingham. This product could be brought to Paducah on barges at a very low freight rate.

There are several valuable clay deposits in the Purchase and some of these should prove suitable for the second constituent of the cement mixture. A careful chemical analysis would be required for each clay.

The advantages for locating a Portland cement plant at Paducah may be listed as follows:

1. The low cost of transportation of the requisite limestone by water.
2. The ample supply of water for all purposes.
3. The close proximity to an extensive coal field as a source of fuel.
4. The railroads that can transport the finished product to consuming points.
5. The Ohio, Mississippi, and Tennessee Rivers to handle on barges the finished product.

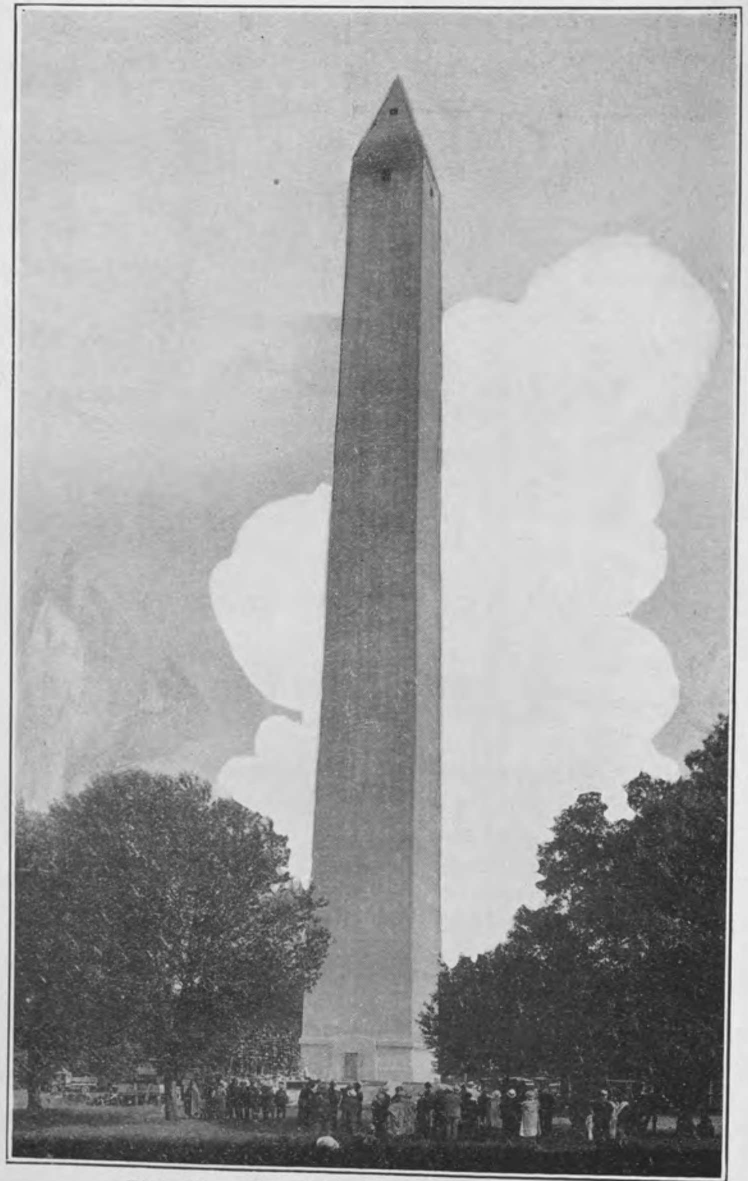


FIG. 33. JEFFERSON DAVIS MONUMENT
Elkton, Todd County, Kentucky.

CHAPTER IX.

CHEMICAL ANALYSES

The object in presenting a chapter on the chemical analyses of various limestones, clays and shales, in this report is to show that the state of Kentucky has within its borders in widely distributed areas a great variety of rocks, whose chemical composition falls well within the range required in the manufacture of Portland cement. To know the chemical composition of a limestone, clay or shale, before it is used in the cement mixture, is absolutely essential, for the composition of the mix must be correct in order to ensure a sound finished product. The analyses furthermore, will reveal several localities where the limestones are especially low in their magnesium carbonate content, and high in their calcium carbonate content and therefore especially well suited for use in the manufacture of Portland cement.

None of the analyses have been made by the author. Most of them have been made in the laboratories of the Kentucky Experiment Station under the direction of Dr. A. M. Peter. Where the actual analyst is known, his name is given.

ANDERSON COUNTY

	Per cent
Silica, SiO_2	10.42
Alumina, Al_2O_3	2.03
Calcium Carbonate, $CaCO_3$	85.20
Magnesium Carbonate, $MgCO_3$	1.24
Alkalies, K_2O, Na_2O	.79
Sulphur trioxide, SO_3	.17
Total	99.85

Dr. Robert Peter, analyst.

BARREN COUNTY

Labratory No. 61757. Sample from the Harvey Quarry near Glasgow. The sample was about a pound lump of neutral gray, cyrstalline limestone, especially low in magnesium carbonate content.

	Per cent
Calcium carbonate, $CaCO_3$	92.1
Magnesium corbonate, $MgCO_3$	0.4
Impurities by difference	7.5
Total	100.00

No. 1421. Oolitic limestone from Glasgow Junction. This limestone was compact, nearly white and oolitic.

	Per cent
Cadcium carbonate, $CaCO_3$	98.050
Magnesium carbonate, $MgCO_3$	.363
Alumina, oxides of iron, etc., Al_2O_3, Fe_2O_3	.511
Phosphoric acid, P_2O_5	.051
Sulphur Dioxide, SO_3	.260
Potash, K_2O	.115
Soda, Na_2O	.327
Silicia and insoluble silicates	1.063
Total	100.737

Analyst, Dr. Robert Peter.

BARREN COUNTY

	Per cent
Silica, SiO_2	1.06
Alumina, Al_2O_3, and iron oxide, Fe_2O_3	.51
Calcium carbonate, $CaCO_3$	98.05
Magnesium carbonate, $MgCO_3$	.36
Alkalies, K_2O and Na_2O	.44
Sulphur Trioxide, SO_3	.26
Total	100.68

This analysis was taken from Rept. Ky. Geol. Survey, A, Vol. 2, 1885.

BOURBON COUNTY

The above sample was taken from Cane Ridge, Bourbon County.

	Per cent
Calcium carbonate, $CaCO_3$	97.540
Magnesium carbonate, $MgCO_3$	.699
Alumina, Al_2O_3, iron oxide, Fe_2O_3, etc.	.287
Phosphoric acid, P_2O_5	.093
Sulphur trioxide, SO_3	.180
Potash, K_2O	.065
Soda, Na_2O	.206
Insoluble silica and silicates	1.446
Total	100.516

Dr. Robert Peter, Analyst.

BRECKINRIDGE COUNTY

Oolitic limestone from the Webster Stone Company. Breckinridge County. Analysis of the air-dry sample.

	Per cent
Moisture	0.000

	Per cent
Ignition	43.652
Silicia, SiO_2	.380
Alumina, Al_2O_3	.040
Ferric Oxide, Fe_2O_3	.086
Calcium Oxide, CaO	53.540
Ferrous oxide, FeO	.000
Magnesium oxide, MgO	.300
Phosphorus pentoxide, P_2O_5	.002
Sulphur trioxide, SO_3	.000
Titanium dioxide, TiO_2	.000
Total	100.000

	Per cent
Calcium corbonate, $CaCo_3$, equivalent to the calcium oxide	99.11
Magnesium carbonate, $MgCO_3$, equivalent to magnesium oxide	.38
Total calcium and magnesium carbonates	99.49

Analysis by the Ashland Iron and Mining Company, Ashland, Ky.

CARTER COUNTY

This sample was collected at Hayward, Carter County

	Per cent
Silica, SiO_2	1.15
Alumina, Al_2O_3, and Iron oxide, Fe_2O_3	.65
Calcium carbonate, $CaCO_3$	97.15
Magneisium carbonate, $MgCO_3$	.93
Total	99.88

CARTER COUNTY

Laboratory No. G-2849. Limestone from quarry on north side of track just west of Tygart, Carter County, Ky.

Analysis of air-dry sample	Per cent.
Moisture	.05
Ignition	42.15
Silica, SiO_2	1.64
Alumina, Al_2O_3	.38
Ferric oxide, Fe_2O_3	.48
Calcium oxide, CaO	54.88
Magnesium oxide, MgO	.32
Phosphorus pentoxide, P_2O_5	trace
Total	99.90

Calcium carbonate, $CaCO_3$, equivalent to the calcium oxide	97.10
Magnesium carbonate, $MgCO_3$, equivalent to the magnesium oxide	.67
Total calcium and magnesium carbonates	97.77

FAYETTE COUNTY

Kentucky Marble (Birdseye). Tyrone formation, 14½ miles from Lexington, Ky.

	Per cent
Calcium carbonate, $CaCO_3$	95.680
Magnesium Carbonate, $MgCO_3$	2.044
Alumina, Al_2O_3, iron oxide, Fe_2O_3, etc.	.380
Phosphorus pentoxide, P_2O_5	.182
Sulphur trioxide, SO_3	.166
Potash, K_2O	.193
Soda, Na_2O	.048
Silica, SiO_2, and insoluble silicates	1.580
Total	100.273
Total calcium and magnesium corbonates	97.724

Dr. Robert Peter, Analyst.

FAYETTE COUNTY

	Per cent
Silica, SiO_2	1.58
Alumina, Al_2O_3, and Iron oxide, Fe_2O_3	.38
Calcium carbonate, $CaCO_3$	95.68
Magnesium carbonate, $MgCO_3$	2.04
Alkalies, K_2O, and Na_2O	.24
Sulphur trioxide, SO_3	.17
Total	100.09

Dr. Robert Peter, Analyst.

FRANKLIN COUNTY

	Per cent
Silica, SiO_2	2.08
Alumina, Al_2O_3, and Iron oxide, Fe_2O_3	.77
Calcium carbonate, $CaCO_3$	95.38
Magnesium carbonate, $MgCO_3$	1.51
Alkalies, K_2O and Na_2O	.14
Sulphur trioxide, SO_3	.58
Total	100.46

Dr. Robert Peter, Analyst.

GRAYSON COUNTY

This sample was collected at Leitchfield, Grayson County.

	Per cent
Silica, SiO_2	0.49
Alumina, Al_2O_3, and Iron oxide, Fe_2O_3	.22
Calcium carbonate, $CaCO_3$	97.63
Magnesium carbonate, $MgCO_3$	.65
Sulphur trioxide, SO_3	.34
Total	99.33

The above analysis was taken from 20th Ann. Rept. U. S. Geol. Survey, Pt. 6, 1899.

MARSHALL COUNTY

The following analyses were made from the clays of the Paducah Clay Company.

Paducah Clay Company	1	2	3	4
Silica, SiO_2	55.90	65.10	63.20	60.60
Alumina, Al_2O_3	26.35	22.18	23.32	25.06
Iron oxide, Fe_2O_3	2.24	1.28	1.22	1.36
	84.48	88.56	87.74	87.02
Ratio	1:1.9	1:2.7	1:2.5	1:2.3

Certain components of these clays do not appear to have been determined, but they would have to be known were the clays to be used in manufacture of Portland cement.

MEADE COUNTY

Laboratory No. 7-2873. Sample from No. 1 quarry, Meade County, Kentucky.

Analysis of air-dry sample.	Per cent
Moisture	.05
Ignition	43.32
Silica, SiO_2	1.78
Alumina, Al_2O_3	1.14
Ferric oxide, Fe_2O_3	.48
Ferrous oxide, FeO	.00
Calcium oxide, CaO	52.40
Magnesium oxide, MgO	1.04
Phosphorus pentoxide, P_2O_5	trace
Sulphur trioxide, SO_3	trace
Titanium dioxide, TiO_2	.00
Total	99.21
Calcium carbonate, $CaCO_3$, equivalent to the calcium oxide	93.57

Magnesium carbonate, $MgCO_3$, equivalent to the magnesium oxide	2.18
Total calcium and magnesium carbonate	95.75

Analysis by J. S. McHargue.

POWELL COUNTY

Laboratory No. 9-2914. Limestone for Portland cement, Patrick Cement Company, Powell County.

Analysis of the air-dry sample.	Per cent
Moisture	0.06
Ignition	43.10
Silica, SiO_2	1.52
Alumina, Al_2O_3	.18
Ferric oxide, Fe_2O_3	.48
Ferrous oxide, FeO	.00
Calcium oxide, CaO	53.20
Magnesium oxide, MgO	.50
Phosphorus pentoxide, P_2O_5	trace
Sulphur trioxide, SO_3	.00
Titanium dioxide, TiO_2	.00
Total	99.04
Calcium carbonate, $CaCO_3$, equivalent to the calcium oxide	95.07
Magnesium carbonate, $MgCO_3$, equivalent to the magnesium oxide	1.05
Total calcium and magnesium carbonate	96.12

Analysis by J. S. McHargue.

ROCKCASTLE COUNTY

Laboratory No. G-2606.

Analysis of air-dry sample.	Per cent.
Moisture	0.11
Ignition	43.78
Silica, SiO_2	.27
Ferric oxide, Fe_2O_3, Alumina, Al_2O_3, etc.	.41
Lime, CaO	54.82
Magnesia, MgO	.55
Sulphur trioxide, SO_3	.02
Phosphorus pentoxide, P_2O_5	trace
Total	99.96
Calcium carbonate, $CaCO_3$, equivalent to calcium oxide	97.89

Analysis by S. D. Averitt.

WARREN COUNTY

Laboratory No. G-3030. Sample sent by the Franklin Concrete Company from their quarry near Woodburn, Warren County, Kentucky.

Analysis of air-dry sample.	Per cent	
Moisture	0.00	
Ignition	43.50	
Silica, SiO_2	.90	
Alumina, Al_2O_3	.19	
Ferric oxide, Fe_2O_3	.11	
Ferrous oxide, FeO	.00	
Calcium oxide, CaO	54.60	
Magnesium oxide, MgO	.83	
Phosphorus pentoxide, P_2O_5	.00	
Sulphur trioxide, SO_3	.00	
Titanium dioxide, TiO_2	.00	
Total	100.13	
Calcium carbonate, $CaCO_3$, equivalent to calcium oxide		97.50
Magnesium carbonate, $MgCO_3$, equivalent to magnesium oxide		1.74
Total calcium and magnesium carbonate		99.24

Analysis by J. S. McHargue.

WOODFORD COUNTY

Laboratory No. G-3445. Sample collected a short distance west of the Old Crow Distillery, Woodford County, Kentucky.

Analysis of air-dry sample.	Per cent	
Moisture	0.00	
Ignition	43.26	
Silica, SiO_2	1.00	
Alumina, Al_2O_3	.00	
Ferric oxide, Fe_2O_3	.48	
Ferrous oxide, FeO	.00	
Calcium oxide, CaO	53.93	
Magnesium oxide, MgO	.96	
Phosphorus pentoxide, P_2O_5	.42	
Sulphur Trioxide, SO_3	.00	
Titanium dioxide, TiO_2	.00	
Total	100.05	
Calcium carbonate, $CaCO_3$, equivalent to calcium oxide		96.30
Magnesium carbonate, $MgCO_3$, equivalent to magnesium oxide		2.00
Total calcium and magnesium carbonate		98.30

Analysis by J. S. McHargue.

WOODFORD COUNTY

	Per cent.
Silica, SiO_2	0.78
Alumina, Al_2O_3, and Iron oxide, Fe_2O_3	1.04
Calcium carbonate, $CaCO_3$	96.24
Magnesium carbonate, $MgCO_3$	.94
Alkalies, K_2O and Na_2O	.87
Sulphur trioxide, SO_3	.18
Total	100.05

Dr. Robert Peter, Analyst.

CEMENT

Statement of Composition and results of Tests of
PORTLAND CEMENT
Made for Mr. E. D. Wallace, Leeco, Kentucky

The raw materials are:

Shale from Junction City, Ky.,
Clay from Moreland, Ky.,
Limestone from Tyrone, Ky.

Ground dry to pass 30-mesh screen, mixed and wet-ground to pass 20-mesh screen; calcined at 1450C.

Composition of Cement No. 1.

Made from Junction City shale and Tyrone Limestone.

	Per cent.
Alumina	5.10
Iron oxide	2.40
Sulphur trioxide	.15
Potash	.33
Silica	21.10
Magnesia	3.70
Lime	66.90
Total	99.68

Fineness: 98.5% passing 200-mesh screen.

Specific gravity: 3.095.

Setting time: Initial, 4 hours, 10 minutes: Final, 6 hours, 45 minutes.

Tensile breaking stresses:

	Lbs. Neat Briquette
24-hours	330
9-day	1220
19-day	1350
30-day	1380

These briquettes made by mixing 100 parts cement with 22 parts water.

Constancy of volume: Cold, no cracks or hair lines within 45 days.
Hot, small cracks formed, narrow but reaching ⅛th. inch depth.

W. Simonson, Chemist.

Composition of Cement No. 2.

Made from Moreland Clay and Tyrone limestone.

	Per cent.
Alumina	5.15
Iron oxide	2.43
Sulphur trioxide	.10
Potash	.35
Silica	21.55
Magnesia	3.65
Lime	66.32
Total	99.55

Fineness: 98.5%, passing 200-mesh screen.

Specific gravity: 3.137.

Setting time: Initial, 4 hours, twenty minutes: final, 7 hours, 10 minutes.

Tensile breaking stresses for neat briquettes, made from 100 parts cement and 22 parts water:

	Pounds
24-hour	370
9-day	1010
19-day	1310
30-day	1350

Constancy of volume: Cold, no cracks or hair lines within 45 days.
Hot, several small cracks at edges, remainder surface unchanged.

Composition of cement No. 3.

Made from Junction City clay and Tyrone limestone.

	Per cent.
Alumina	5.33
Iron oxide	2.55
Sulphur trioxide	.13
Potash	.32
Silica	21.80
Magnesia	3.85
Lime	66.14
Total	99.82

Fines: 98.5%, passing 200-mesh screen.

Specific gravity: 3.137.

Setting time: Initial, 5 hours, 45 minutes:
Final, 7 hours, 40 minutes.

Tensile breaking stresses for neat briquettes, made from 100 parts cement and 22 parts water:

	Pounds
24-hour	270
9-day	850
19-day	990
30-day	1260

Constancy of volume: Cold, no cracks or hair lines within 45 days. Hot, no cracks or hair lines at edges or any part of the surface.

W. Simonson, Chemist.

CHAPTER X.

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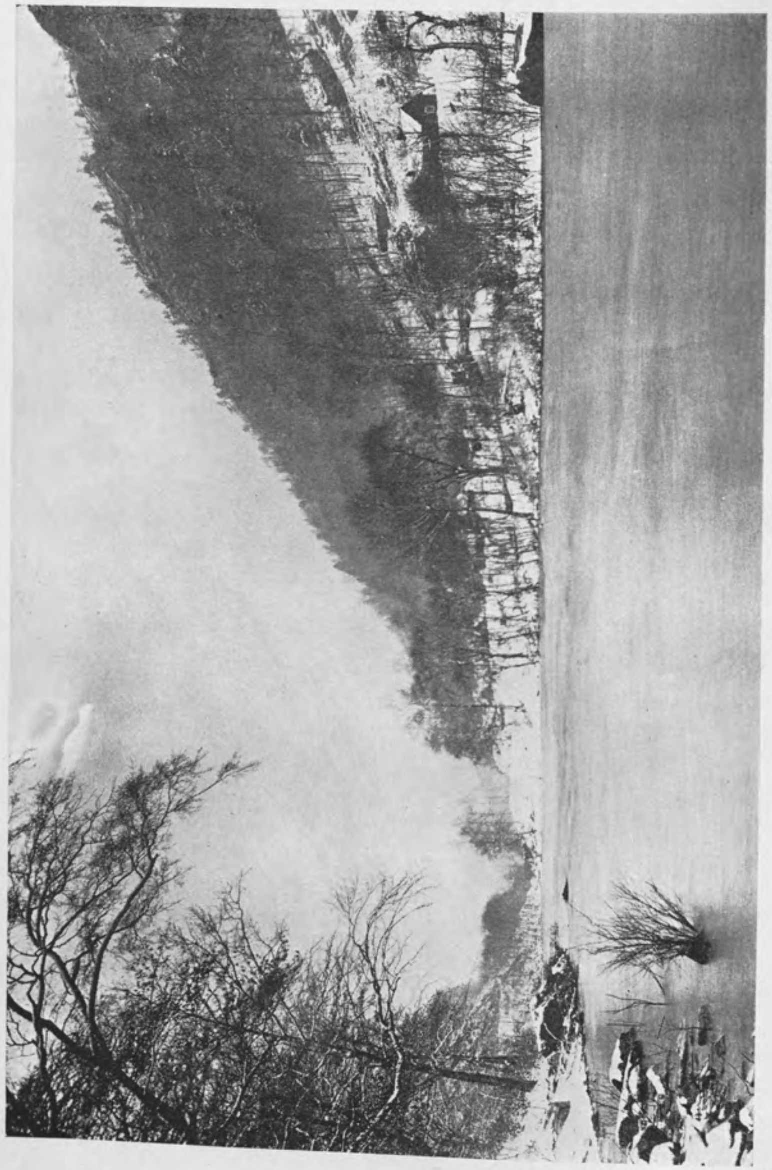
GEOLOGY AND COAL RESOURCES

of the

MIDDLESBORO BASIN IN KENTUCKY



PHOTOGRAPH BY W. R. JILLSON

THE PINEVILLE GAP

The view is up stream in winter. At this point the North Fork of the Cumberland River has trenched its channel transversely across the Pine Mountain uplift and overthrust fault. It is an excellent example of the maintenance of normal regional gradient by a water stream in direct opposition to high angle structure of large figure.

The Geology and Coal Resources *of the* Middlesboro Basin in Kentucky

By

CHESTER K. WENTWORTH

Assistant Geologist

Illustrated With Thirty-One Photographs, Maps and Diagrams

KENTUCKY GEOLOGICAL SURVEY
FRANKFORT, KY.
1927

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THE GEOLOGY AND COAL RESOURCES OF THE MIDDLESBORO BASIN IN KENTUCKY.

By Chester K. Wentworth, Ph. D.

INTRODUCTION

Location and Extent of Field

The area described in this report consists of that portion of the bituminous coal field of the eastern United States which lies between Pine Mountain and Cumberland Mountain and which is contained within the state of Kentucky. It has an extreme length of about 80 miles, an average width of 10 miles and comprises a total of 727 square miles. Of this total 52 square miles lie in Letcher County, 421 in Harlan County and 254 in Bell County. Harlan, situated at about the center of the field is 256 miles by railroad from Cincinnati, 241 from Louisville, 335 from Nashville, 509 from Charleston and 315 from Atlanta.

For 35 miles the southeast border of this district coincides with the southeast border of the Appalachian coal field proper and for 35 miles eastward and northward the district borders on the coal field of southwest Virginia of which the greater part lies in the Virginia portion of the Middlesboro Basin. To the southwest lies a similar portion of the basin in Tennessee and to the northwest stretches the main eastern coal field of Kentucky. See Figure 1.

Purpose and Scope of Report

No detailed recent report on the geology or coal mining operations is available for any part of the district. A part of the district was described by Ashley and Glenn (1)—numbers refer to the bibliography at the end of this report—in 1906, but this report now long out of print is inadequate in view of the present extensive development and consequent wider knowledge of the various coal seams. Other parts were described by Crandall and Sullivan in 1912 (6), Hodge in 1912 (10), and by the same author in 1916 (11). All these reports were written prior to most of the present mining development and are to be regarded as reconnaissance reports.

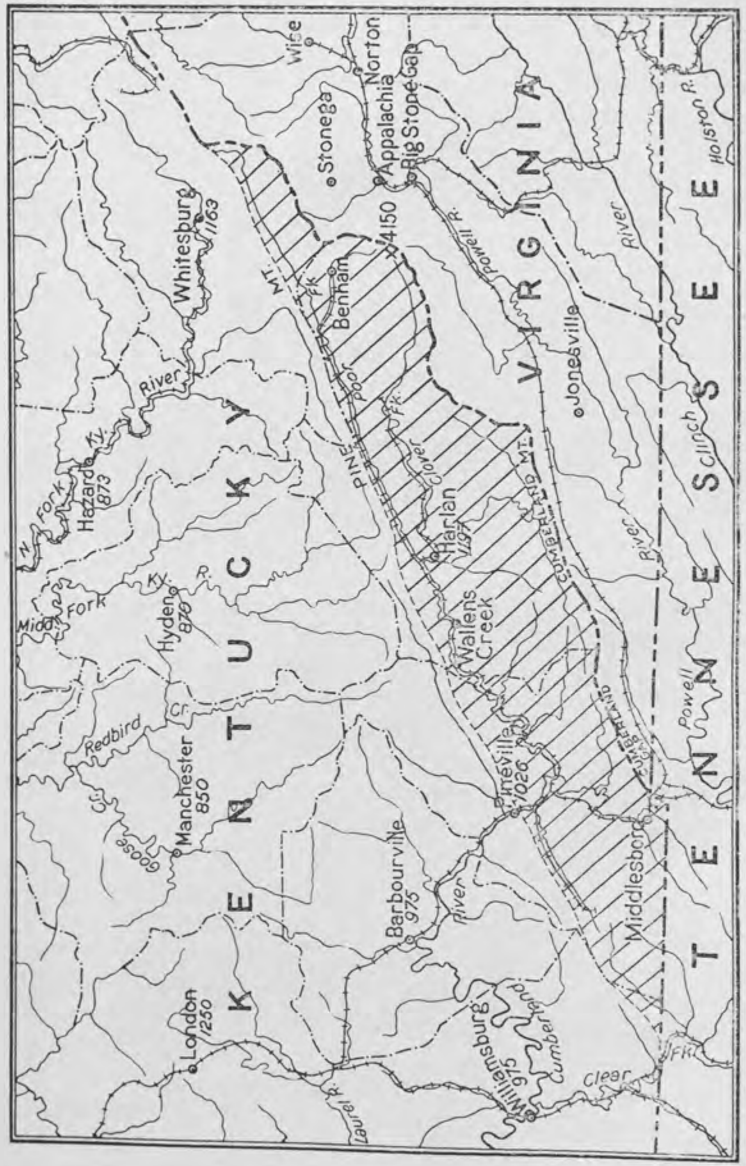

FIG. 1. REGIONAL SETTING OF THE MIDDLESBORO BASIN

In view of the lack of an adequate detailed report of modern conditions and knowledge of this important field the following paper has been prepared as a preliminary statement of salient features. It is to be followed by a series of complete reports on the district by counties as a part of the survey of the entire eastern coal field of the state. This report is based in part on two months of field work in June, July and August, 1925, but a large part of the data is from the several previous reports named and supplemented by the series of detailed county reports published by the Virginia Geological Survey for the adjacent coal field of southwest Virginia (7, 9).

The principal purpose of the field work in 1925 was the drawing of areal boundaries between the Pottsville and Allegheny divisions of the Pennsylvanian and the mapping of the top of the Lee conglomerate formation within the Pottsville for publication on the new geologic map of the state. In addition to this reconnaissance, three weeks were devoted to detailed study of the Pensylvanian rocks in the vicinity of Lynch. Considerable progress in road improvement and the increasing use of automobiles in this mountainous district made it possible for the writer to travel between the principal points by car and greatly facilitated covering the region in a reconnaissance way.

ACKNOWLEDGMENTS

In the course of field work assistance was rendered by various residents to all of whom the writer's thanks are due. Mr. Fred W. Stout, Engineer of the U. S. Coal and Coke Co., at Lynch, and Mr. Wm. H. Boatright, Engineer of the Wisconsin Steel Co., at Benham were especially helpful in placing at the writer's disposal much detailed information on the coal resources and structure in the basin of Big Looney Creek. Mr. P. M. Sherwin, Mining Engineer, of Pineville, aided the writer's field work in a number of ways and through his directory of coal operations in eastern Kentucky was of material assistance in the compilation of data on present development (13). Most of all the writer was aided by Mr. James Hudnall of this Survey, who spent about a week in the field in consultation on the structural problems and in gaining a familiarity with the coal measures of the Middlesboro Basin and adjacent parts of Virginia. Mr.

Hudnall's extensive knowledge of the main coal field of eastern Kentucky made his suggestions and criticisms of especial value and the correlation table given on page 186 was contributed by him, the present writer having had no experience in the coal measures northwest of Pine Mountain.

PHYSIOGRAPHY

Relation to Broad Provinces

The eastern United States is made up of a series of linear physiographic provinces extending from northeast to southwest. Named from the east coast westward these are: Atlantic Coastal Plain, Piedmont Plateau, Blue Ridge, Appalachian Valley, Cumberland-Allegheny Plateau (8). The characteristic topography of these provinces as well as their linear, belted arrangement is controlled by the folded and faulted structure of the rocks of the Appalachian region together with the subsequent influence the resulting mountains have exerted in developing adjacent linear provinces such as the present Coastal Plain.

The Middlesboro basin is a part of the Cumberland Plateau and is made up over most of its area of horizontal rocks of Pennsylvanian age. It is separated from the main area of the Cumberland Plateau, however, by the monoclinal ridge of Pine Mountain, and lies between Pine Mountain and Cumberland Mountain, the latter being the normal southeast margin of the plateau. Because of its situation, enclosed between two resistant mountain barriers for many miles, the Middlesboro basin contains the most lofty and rugged topography of this portion of the Carboniferous plateau and occupies a nuclear position with respect to drainage, sending its waters through five major drainage systems by widely divergent routes to the Mississippi River. See Fig. 2.

Minor Districts Within the Middlesboro Basin

In the Kentucky portion of this basin are a number of physiographic districts. The long narrow south flank of Pine Mountain is the most strongly characterized. Cumberland Mountain constitutes a similar district on the south side of the basin. From Flat Gap where the state line turns south from Pine

Mountain to Harlan and Martin's Fork of the Cumberland River is the Black Mountain district. South and west of Pineville and extending to the Tennessee line is a district known as the Log Mountains. Between the Log Mountain and Black Mountain districts is a region which is less easily defined but which will here be called the Wallins Creek district.

Most of these districts have pronounced topographic individuality. Pine Mountain and Cumberland Mountain are dominated by the dipping beds of the Lee formation, the consequent courses of the minor streams and the flanking strike courses of the major streams. Black Mountain district together with the corresponding Virginia area is the area of high summits for this part of North America, consisting of horizontal coal measures deeply dissected to a drainage pattern which is dendritic in its details but roughly radial in its broad outlines. The Wallins Creek district is similar to the Black Mountain district, but less rugged. The Log Mountain district is a region of dendritic drainage in detail but its major outlines are more anomalous than those of the Black Mountain section and appear to have been in part controlled by faulting and folding.

Drainage

The entire Kentucky portion of the Middlesboro Basin is drained by the Cumberland River, practically all through the Pineville Gap but a small area at the southwest end being drained by Clear Fork which enters the Cumberland at Williamsburg. Cumberland River with its head tributary, Poor Fork, flows for sixty miles along the foot of Pine Mountain from Flat Gap to Pineville. (Figures 3, 4, 6, 7.) From the north it receives water from scores of short and nearly uniform tributaries which flow off the flank of Pine Mountain at intervals averaging a half-mile. From the south enters a series of tributaries increasing in length to the southwest as the position of the Cumberland-Tennessee divide shifts progressively southward from Pine Mountain across Flat Gap, along Black Mountain to the Doubles and thence along Little Black Mountain to Cumberland Mountain. By name the principal of these are Franks Creek, Colliers Creek, Big Looney Creek, Clover Lick Creek, Clover Fork, Martin Fork, Wallins Creek, Puckett Creek,

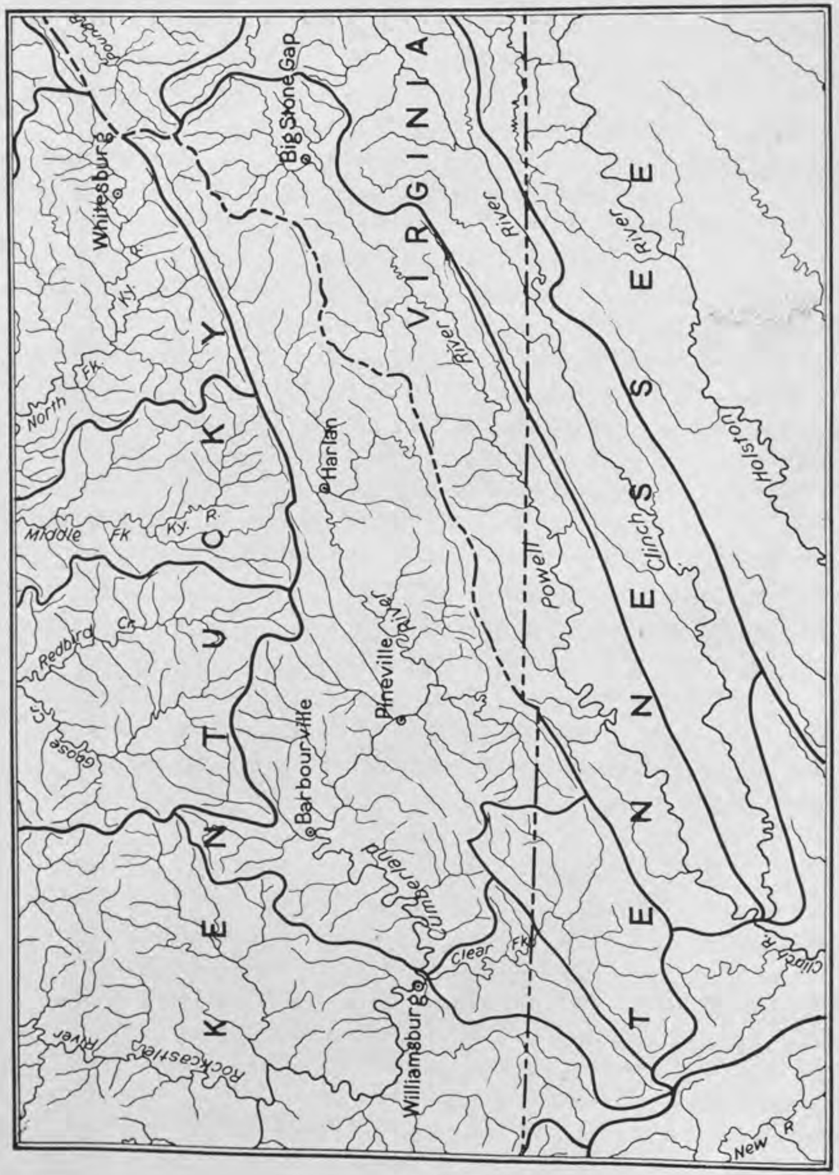

FIG. 2. MAP OF DRAINAGE BASINS.

Brownies Creek, Yellow Creek and Clear Creek. The first four of these head against the divide and drain by nearly straight courses to the Poor Fork. Clover Fork heads far to the east, its valley forming the cleft between Black Mountain and Little Black Mountain, and drains the central portion of the Black Mountain District from the Doubles to Harlan. As a consequence only short, uniform tributaries enter Poor Fork from the south in the twenty miles between the mouths of Clover Lick and Clover Fork. Martins Fork with its tributary, Cranks Creek, flanks the north slope of Cumberland Mountain for over twenty miles and drains a considerable part of the Black Mountain and Wallins Districts south of Harlan. Yellow Creek drains much of the area from Pineville southeast, south and southwest and its tributaries Clear Creek and Little Yellow Creek flank the Cumberland Mountain slope for a number of miles on either side of Cumberland Gap. The opposed heads of Martins Fork and Clear Creek of Yellow Creek are less than a mile apart and none of the tributaries entering Cumberland River between Harlan and the mouth of Yellow Creek head back to Cumberland Mountain.

Clear Creek enters the Cumberland at the entrance to Pineville Gap and flanks the south slope of Pine Mountain for thirteen miles to the westward. Laurel Fork of Clear Fork, tributary to the Cumberland River at Williamsburg, flanks Pine Mountain from this point southwestward to the Tennessee line and Clear Fork proper drains a small central part of the basin west of Middlesboro.

The nuclear character of the Black Mountain region is well shown by the drainage of adjacent areas in Virginia and in Kentucky north of Pine Mountain. From a point opposite Harlan northeastward the drainage north of Pine Mountain goes successively to the middle and north forks of Kentucky River and the Russell Fork of Sandy River, all tributary to the Ohio. In Virginia at a point about three miles south of Flat Gap in an area of not over two square miles are contained the heads of streams flowing to the Big Sandy River, the Clinch River, the Powell River and the Poor Fork of Cumberland River. Southwestward from this point the drainage of areas adjacent to the Middlesboro is to the Powell River, tributary of the Tennessee River.

FIG. 3. CUMBERLAND RIVER VALLEY.

The importance of Pine and Cumberland Mountains in maintaining the high elevations of the Middlesboro Basin is well shown by the influence of water gaps in these mountains on the positions of the divide between north and south drainage. For a considerable distance to the southwest and for many miles to northeast the control of the Pineville Gap is supreme and north drainage reaches to southward limits of the basin. North of Pennington Gap the streams of the Pocket have pushed the Little Black Mountain divide northward in competition with the tributaries of Martin and Clover Forks. North of Big Stone Gap is a similar and larger lobate extension of south drainage. Farther east Stone Mountain declines into the horizontal coal measures and is no longer a barrier. In spite of this seeming advantage to south drainage the control of the Breaks of Sandy Gap in Pine Mountain is seen in a great lobate deployment of the tributaries of the Russell Fork of Big Sandy River. (Figures 2.)

Discussion of the origin of this drainage and of the physiographic features of the upland is beyond the scope of this paper and the reader is referred to the work of Hayes and Campbell, and Ashley and Glenn. (1, 17.)

Detailed Topography

For contour maps of this region see U. S. G. S. topographic atlas sheets as follows Pound, Whitesburg, Estillville, Big Stone Gap, Nolansburg, Harlan, Middlesboro, Jonesville, Hagan, Sneedville, Cumberland Gap and Williamsburg.

Pine Mountain

Everywhere along its length the contrast between Pine Mountain and the adjacent topography of the Cumberland Plateau is striking. The linear character of its crest, its abrupt northern face and its gentler pine covered southern slope with its great dipping rock pinnacles and crags give it a surprisingly uniform character during the entire 125 miles of its length, and set it apart from the rugged but seeming aimless maze of dendritic topography of the plateau. (Figure 5.)

The Kentucky-Virginia line turns southward from the crest of Pine Mountain at Flat Gap where it passes along a low col between the headwaters of Pound River, tributary to Russell

Fork of Big Sandy River on the Virginia side and the headwaters of the Poor Fork of Cumberland River on the Kentucky side. From this point southwestward the South flank of Pine Mountain lies in Kentucky and hence falls within our province Here the Pine Mountain crest rises to 3,265 feet A. T. (above tide), the highest point in its entire length. East of the Flat Gap

FIG. 4. PINEVILLE GAP.

col the crest lies generally between 2,750 and 3,000 feet above sea level, with a number of peaks exceeding 3,000 feet and having several gaps cut down to under 2,500 feet. From Flat Gap westward to Hurricane Gap the crest presents a nearly even skyline declining at an average rate of about ten feet to the mile for nearly twenty miles. This section is cut by several gaps to depths of two or three hundred feet but has no high peaks. West of Hurricane Gap is a section of about twenty-five miles in length marked by higher peaks and deeper notches and ending at Salt Trace Gap (2,219 feet). The topography of the Pine Mountain crest is less well known west of this point because it has been mapped only on the smaller scale of older maps but it appears quite certainly to be free from conspicuous peaks and very deep gaps all the way to the state line east of Jellico except for the deep water gap through which the Cumberland River flows northward at Pineville. Throughout this distance though the

crest varies through ranges of one or two hundred feet locally it falls at an average of slightly less than ten feet per mile.

Cumberland Mountain District

The crest of Cumberland Mountain forms the Kentucky-Virginia state line from the Lee County district known as The

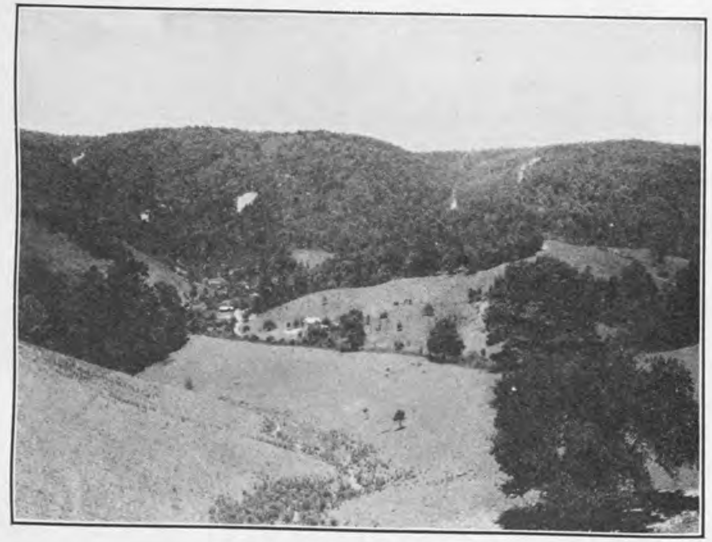

FIG. 5. PINE MOUNTAIN.

Pocket southwest to Cumberland Gap and thence after controlling the Kentucky-Tennessee line in a two-mile jog passes into Tennessee. Along the Kentucky portion the higher parts of the ridge reach 2,500 to 2,700 feet with the exception of about ten miles of the crest south of the heads of Martins Fork and Brownies Creek which stands continuously above 3,000 feet and culminates in a peak reaching over 3,400 feet at the Bell-Harlan County line. Cumberland Mountain is similar in its general topography to Pine Mountain but varies more throughout its length and is less continuously flanked by through-flowing streams. For many miles southwestward from Pennington, Va., its bold mass stands as an almost unbroken wall which dominates the rolling valley lands at its southeast foot. (Figure 8.)

Black Mountain District

The main crest of Black Mountain extends from near Flat Gap southwest to a culminating point known as the Doubles which stands at the heads of Big Looney Creek, and Clover Fork of Cumberland River drainage and Little Looney Creek of Powell River drainage in Virginia. This point has an elevation

FIG. 6. POOR FORK VALLEY.

of 4,150 feet and from it, high, continuous spurs radiate northwest and southwest. The state line follows Little Black Mountain which extends to the southwest and constitutes the watershed between Powell River drainage and that of the Clover Fork of Cumberland River. For three or four miles Little Black Mountain maintains elevations of 3,000 to 4,000 feet but declines to 2,500 feet for several miles south of the head of Clover Fork. North of The Pocket it again reaches, 3,000 feet and continuing westward as the divide between Clover Fork and Martins Fork maintains elevations generally over 3,000 feet until it comes to an end three miles southeast of Harlan.

Black Mountain proper extends west from the Doubles with elevations of 3,500 to over 4,000 feet for about ten miles passing between the basins of Cloverlick Creek and Clover Fork. From Cloverlick Creek southwestward Black Mountain forms the south wall of the valley of Poor Fork as far as Harlan with summit elevations declining slowly from 3,500 to 2,500 feet. Benham Spur is a high ridge extending with elevations in excess of 3,500

feet northwest from the Doubles between Cloverlick and Big Looney Creeks. (Figures 9, 10 and 11.) A similar but narrower spur extends west from Black Mountain between Big Looney Creek and the upper course of Poor Fork. In the Black Mountain district is found the maximum relief of the Kentucky portion of the Allegheny-Cumberland Plateau. Poor Fork, the master stream of the region, flows from an elevation of about 1,500 feet at the Harlan-Letcher county line to under 1,200 feet at Harlan and is overlooked by Black Mountain summits 1,500 to 2,000 feet higher at distances not over one and a half or two miles through much of this course. The principal tributaries of Cumberland River and Poor Fork have cut their valleys below 2,000 feet far up their courses and are in many places flanked by nearly continuous mountain slopes of 2,000 feet. The drainage pattern of the minor streams and pattern of the topography in detail is a typical dendritic one; the courses of the larger streams are in part influenced by the linear Pine Mountain and Cumberland Mountain structures. Taken in its details the topography of this region is in typical maturity showing maximum relief, steepness of slopes and completeness of drainage net. The almost complete distinction of flat summit areas with the practical absence as yet of considerable flat bottom lands places the region in almost precisely the middle stage of topographic development.

Wallins Creek District.

The topography of the Wallins Creek District differs in no essential respect from that of the Black Mountain district in its details. It is maturely dissected with no summit flats and the same dendritic drainage pattern as the Black Mountain district. The pattern of the Major drainage pattern differs from the district to the east in that the Cumberland River swings more widely in broader and more subdued bottomland topography rather than taking the straight course along the Pine Mountain foot so notable east of Harlan. Moreover, the Wallins Creek district is drained more directly across the basin from south to north by a series of short creeks rather than by streams having longer and rudely linear courses such as those of Clover Fork and parts of Martins Fork and Cloverlick Creek. As a result

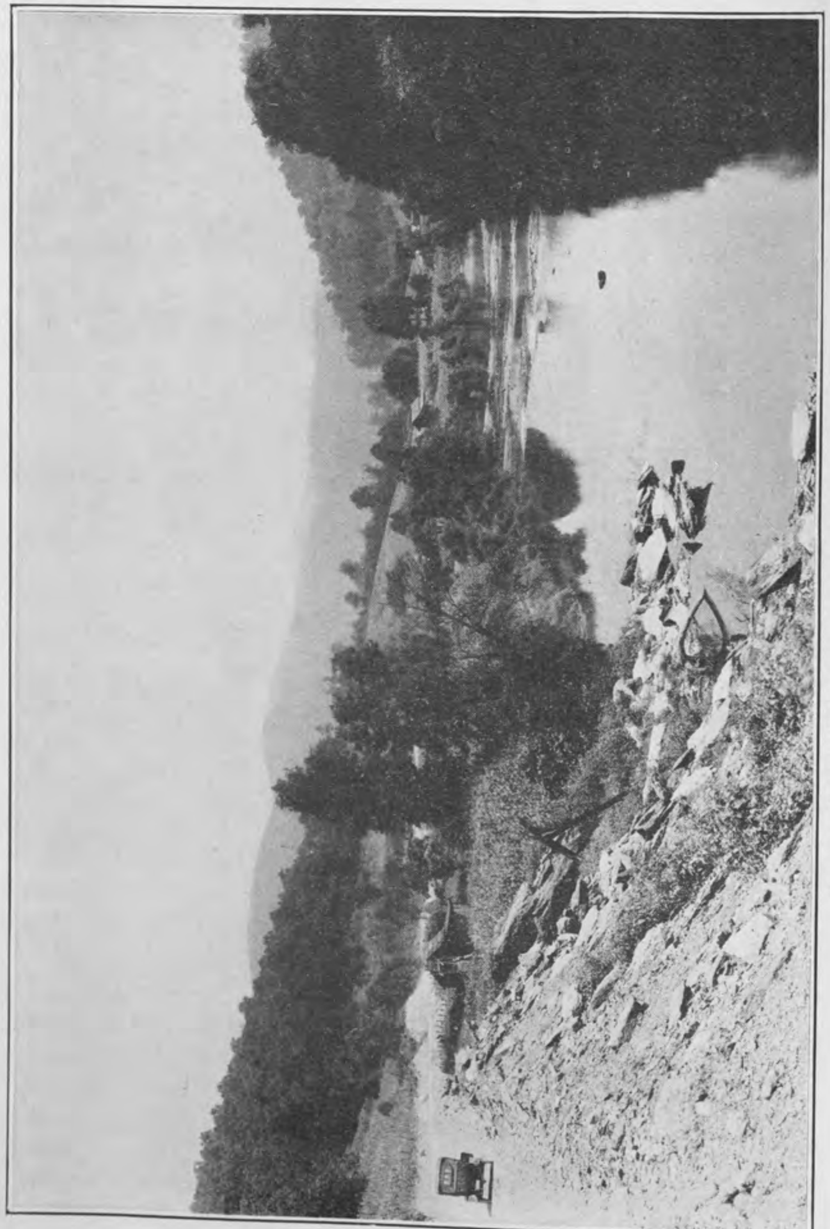

FIG. 7. UPPER CUMBERLAND RIVER VALLEY.

long mountain masses corresponding to the Little Black and Black Mountains are absent in the Wallins Creek district but their places are taken by shorter, mostly north-south ridges of but slightly inferior elevation, considerable areas in the section south of Wallins Creek town reaching 3,000 feet or more. Westward toward Yellow Creek the summit elevations are less, reaching 2,000 feet in but few places.

FIG. 8. CUMBERLAND MOUNTAIN.

Log Mountain District

The Log Mountain District is less well known to the present writer than the area to the east and much of the information here presented is taken from the published report of Ashley and Glenn (1). In a broad way the local topography of the Log Mountain district is similar to that of the districts described above. The broader drainage pattern and the arrangement of main ridges is rudely radial, the drainage going southwest to tributaries of Clear Fork, east and south to tributaries of Yellow Creek and north and northeast to Clear Creek. According to Ashley and Glenn the stream profiles west of Rocky Face and hence comprising the whole of the Log Mountain district are of more uniform grade and less concave in their upper portion than are those east of Rocky Face. In the same report it is pointed out that the ridge tops in the Log Mountain district are more rounded and less sharp crested than those to the east. For fur-

ther details and explanation of these features as well as a discussion of the probable origin of the Middlesboro plain and the thick alluvial deposits which mantle, the reader is referred to their report. (1-pp. 14-30.) The conspicuous monoclinal ridge of Rocky Face lying almost on line between the Pineville and Cumberland Gaps and transverse to the trend of Pine and Cumberland Mountains shows similar features to the latter mountain ridges and is known to have had a similar origin, being formed by the upturned edge of basal Pennsylvanian rocks along a transverse fault.

GENERAL GEOLOGY

Stratigraphy

Description of Formations

General Statement

Rocks exposed in the Kentucky portion of the Middlesboro basin are wholly within the Pennsylvanian system and are confined to the Pottsville and probably a very slight thickness of overlying basal and Allegheny series. The most detailed study of the coal bearing Pennsylvanian rocks of the Cumberland Plateau in this region is that now completed by the Virginia Geological Survey. By virtue of the detailed character of the Virginia studies and their continuity from Tazewell County to Lee County the subdivisions established for these rocks must be accepted ultimately as the standard section for that portion of the Appalachian coal field lying southeast of Pine Mountain. In the absence of detailed studies over most of the area treated in this report it will be impossible to apply the formation names of the Virginia section with strict accuracy to the rocks of the Kentucky area, especially at the southwestern end of the basin. Insofar as possible, however, the names are tentatively applied with the realization that detailed studies may result in minor changes in correlation. The larger part of the material here presented is derived from the published reports of Ashley and Glenn, (1), Eby, (7), and Giles, (9), and from the published report and field studies of the writer in Dickinson, Russell, Wise and Lee counties, Virginia (16, 18).

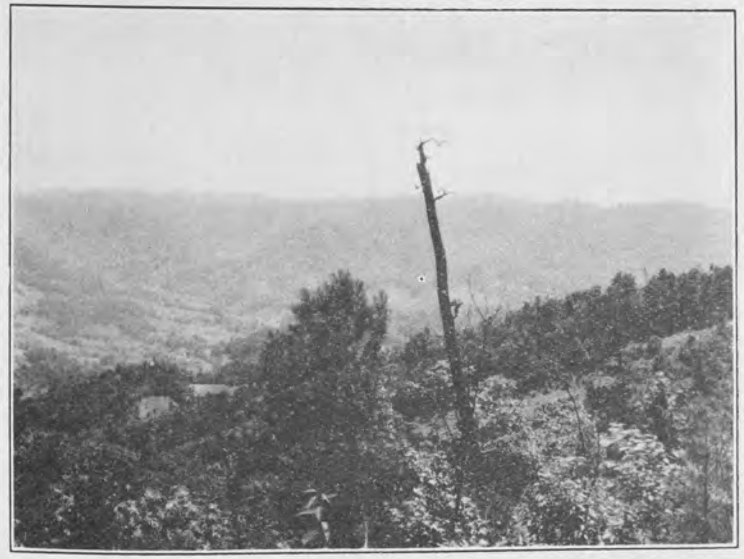

FIG. 9. BLACK MOUNTAIN TOPOGRAPHY.

In the coal field of southwest Virginia the following subdivisions of the Pennsylvanian rocks are recognized:

Harlan formation
Wise formation
Gladeville sandstone
Norton formation
Lee formation

These will be described in the following pages.

Lee Formation.

This formation is typically composed of three massive members of conglomeratic sandstone situated at the top, middle and base of the formation together with intervening sandstone and shale beds and a few thin coal seams, (Figures 12 and 13). It is 1,800 feet thick at Little Stone Gap near Norton, Virginia, and 1,530 feet thick at Big Stone Gap where Campbell has measured the type section, (19).

The formation as thus defined thins rapidly to the northwest and is probably less than a thousand feet thick along Pine

Mountain at the northwest margin of the Middlesboro basin. The conglomerate members of the Lee are hard, resistant rocks and are the most prominent ridge forming beds in the region. The formation forms the resistant crests of both Pine and Cumberland Mountains and is responsible for the controlling position occupied by these monoclinal barriers on two sides of the Middlesboro basin.

FIG. 10. VALLEY OF BIG LOONEY CREEK.

The exact limits of the Lee formation in Pine Mountain or in Cumberland Mountain southwest of Lee county are not known with certainty. Early work of Stone and Butts in the area northeast of that under consideration placed the Lee-Norton contact higher than it is now known to be. (22-p. 12). Ashley and Glenn in their description of the Lee formation express doubt as to both the upper and lower limits in the Cumberland Gap area, (1-p. 33). No final statement on this question can be made at present but the writer is disposed to believe as a result of reconnaissance along Pine and Cumberland Mountains in company with J. S. Hudnall of this survey that the top of the Lee formation as mapped by Ashley and Glenn is likewise too high and that the true Lee-Norton contact is at least three or four hundred feet lower than that indicated by the authorities cited above. It is thought by Mr. Hudnall and the writer that the

true top of the Lee passes under drainage to the north of Poor Fork and Cumberland River along their entire courses and that the formation is nowhere exposed in the gorges of small streams in the central portion of the basin. According to this view, which remains to be checked by detailed work in Harlan and Bell counties, the Naese sand stone is to be regarded as a part of the Norton formation.

NORTON FORMATION

This formation at its type locality consists of from 1,300 to 1,500 feet of sandstone and shale beds with a number of valuable coal beds, (7-p. 66) (Figure 14). In the Russell County portion of the Virginia coal field it is the principal coal bearing formation, farther southwest in Wise and Lee counties it passes under the Wise formation and its coal beds become thinner and less valuable as well as less accessible. Between the central portion of Wise County in the vicinity of Norton and the central portion of the Middlesboro Basin near Harlan the combined thickness of the Lee and Norton decreases from about 3,200 feet to somewhat less than 1,500 feet. If the Naese sandstone be included in the Lee formation following Ashley and Glenn the interval between the Lee formation and the Kellioka-Taggart coal horizon in the Harlan district is about 850 feet. In western Wise County, Va., this interval is 2,400 feet and the interval from the Taggart bed down to the top of the Norton formation is alone over 1,000 feet. It is apparent that a tremendous thinning of the lower Pottsville beds takes place between Wise County and the Harlan district. It is not yet possible to state with certainty whether this thinning takes place mainly in the Norton formation or in all three formations, Lee, Norton and lower Wise. If the correlation of the A bed of the Big Looney Basin with the Imboden of Virginia as made by Bilips and reported with considerable skepticism by Eby (7-pp. 86-87) is correct the Imboden-Taggart interval decreases from over 400 feet to about 220 feet. A proportionate thinning of the 1,000 feet of Wise formation which underlies the Taggart bed in Virginia would account for less than one-third of the total thinning noted above between the Taggart-Kellioka horizon and the top of the Lee and would leave about 1,100 or 1,200 feet to be

accounted for in the Norton formation. This would call for thinning of the Norton to less than 300 feet. It appears most likely to the writer that a considerable part of the thinning has taken place in the Lee and that the Naese sandstone and at least 350 feet of underlying beds belong in the Norton formation. No actual reliable correlations have been made below the Kellioka-Taggart horizon so far as known to the writer but it is thought that the thinning should be distributed somewhat as indicated above and that the most probable position of the top of the Lee is the top of the conglomerate 865 feet below the top of the Big Creek Gap section measured by David White and reported by Ashley and Glenn. (1-p. 36).

The Norton formation as thus tentatively limited includes about 500 feet of shale and sandstone beds described under the Lee formation by Ashley and Glenn and probably little if any of the overlying Hance formation. If the correlation of the conglomerate sandstone of Hodge with the Gladeville sandstone is correct (7-Pl. XIII) and if, as seems likely from its position below the Harlan coal, the conglomerate sandstone corresponds to the top of the Naese sandstone it follows that the entire Hance formation is the equivalent of the lower Wise formation and the Norton is wholly comprised within the Lee formation of Ashley and Glenn.

The Norton formation is not exposed as a horizontal series over most of the middle of the Middlesboro basin. In the Black Mountain district from Flat Gap to Harlan the Norton is wholly under drainage except along the flank of Pine Mountain where it outcrops with dips increasing northward between the nearly horizontal Wise formation of the central basin and the Lee formation which forms the north limb of the syncline. It outcrops similarly in a narrow belt along the remainder of Pine Mountain southwestward to the Tennessee line and along the north flank of Cumberland mountain from the Pocket southwest into Tennessee. In the Wallins Creek district the Norton formation outcrops in the lower valley of Brownies Creek, Hance Creek, Yellow Creek, and on the east flank of Rocky Face. Westward in the Log Mountain district it is below drainage.

As shown by the upper part of the Big Creek Gap section, measured by White, the formation in the western part of the basin consists of alternating shale and sandstone beds in about equal thickness, with few if any workable coal beds. The upper part of the formation as exposed east of Rocky Face consists of the massive Naese sandstone. Along the flanks of Pine Mountain in the eastern basin the formation consists of shale and sandstone with a few coal beds of which little is known in detail.

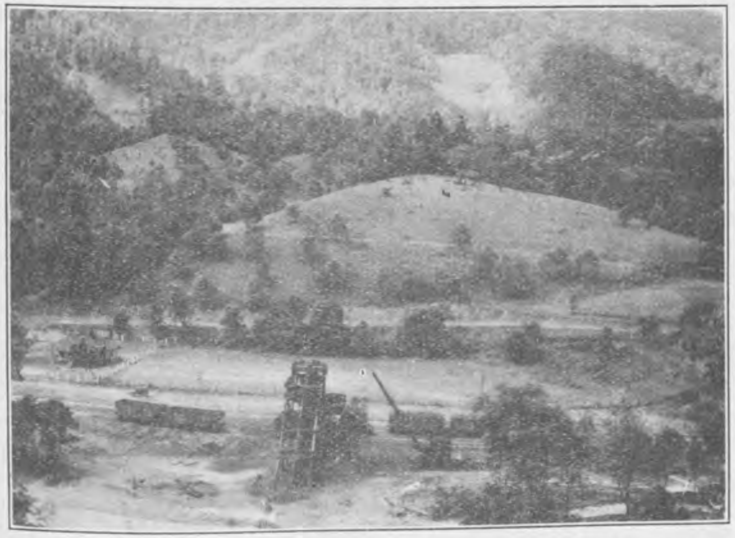

FIG. 11. COAL TIPPLE ON LOWER BIG LOONEY VALLEY.

Wise Formation

The Wise formation consists of over 2,000 feet of sandstone, shale, coal and clay beds with at least one thin limestone bed and perhaps several other calcareous horizons within the shale beds. It is bounded by the Gladeville sandstone below and the Harlan sandstone above. In western Wise County, according to Eby (7-p. 69), it is 2,300 feet thick and thins apparently both northeastward along the strike and northwestward away from the margin of the coal field as shown in part by a section 2,070 feet thick measured by Butts on the South Fork of Pound River in northern Wise County. The formation is here regarded as the equivalent of the Hance, Mingo and Catron formations of the Cumberland Gap area as described by Ashley and Glenn (1).

In this field the thickness of the Wise formation as thus defined averages about 1,900 feet, a thickness not very different from that found by Butts for the place mentioned above and similarly situated with relation to Pine Mountain and the general margin of the coal field. Data given by Ashley and Glenn for the thickness of the Mingo and Catron formations indicate that the coal measures of this part of the section thin rapidly to the northwest toward Pine Mountain, the rate of thinning being apparently in some sections as great as three or four per cent to the mile. The rate of thinning indicated by the two thicknesses given above for Wise County is much less, not over one per cent. (Figures 15, 16 and 17).

In Wise County the formation consists of about one-third sandstone and two-thirds shale and clay, with the sandstone beds slightly more abundant near the top and bottom than in the middle. The clay beds are in places buff or red and intricately color banded in a pattern having no apparent relation to the bedding. Except for the greater abundance and value of the coal beds in the Wise formation it differs but little from the underlying Norton formation and cannot be discriminated from it except by its position with reference to known key horizons. So far as the Wise formation of the Black Mountain district of Kentucky is known, it has the same character as in Virginia. At a few localities in the higher parts of Black Mountain a black, fossiliferous limestone bed about one foot in thickness has been found which will probably be of considerable stratigraphic value in carrying detailed correlations from Wise County southwestward thought it has not been reported in place at any considerable distance from Wise County. It is about 175 feet below the Pardee coal bed and about 620 feet below the top of the Wise formation (7-p. 163). At several horizons nearer the base of the Wise formation and between 1,400 and 2,500 feet elevation in the north slope of Black Mountain near Nolansburg, the writer found calcareous concretions of septarian forms up to four feet in diameter and in places these were so continuous as to form a one or two foot zone of limestone. Similar concretions are mentioned by Ashley and Glenn (1-p. 31), and some one or more of these zones may prove to be identifiable over considerable areas when detailed studies are made.

Taken as a whole, the Hance, Mingo and Catron formations of the Cumberland Gap field are similar to the Wise formation of the eastern part of the basin though the Mingo and Catron formations appear to contain a larger proportion of cliff forming sandstones than does the middle and upper Wise formation farther east. These formations contain nearly all the important coal beds of the region, the coal beds being somewhat more abundant in the upper part of the series than in the lower.

FIG. 12. LEE CONGLOMERATE, PINE MOUNTAIN NEAR POOR FORK.

HARLAN FORMATION

In the highest parts of Black Mountain along the Wise County line at least 900 feet of coal-bearing rocks lie above the Wise formation and have been described as the "Harlan sandstone" (7-pp. 70-71). The basal member is a sandstone about 30 feet thick which weathers out in platy layers to form as wall-like pile of almost artificial aspect (Figure 18). Above this is about 100 feet of massive and slightly conglomeratic sandstone which forms high cliffs. As described by Eby (7-pp. 70-71), the overlying measures to an additional thickness of 550 feet are sandy shale and thin bedded sandstones and still higher sandstones become more prominent. In the Cumberland Gap field the Harlan formation is thought to be represented by the coal measures included in the Hignite and Bryson formations (1-pp. 43-44). The Reynolds sandstone member of the Hignite is thought to be the equivalent of the massive cliff-forming sandstone near the base of the Harlan formation and is described by Ashley

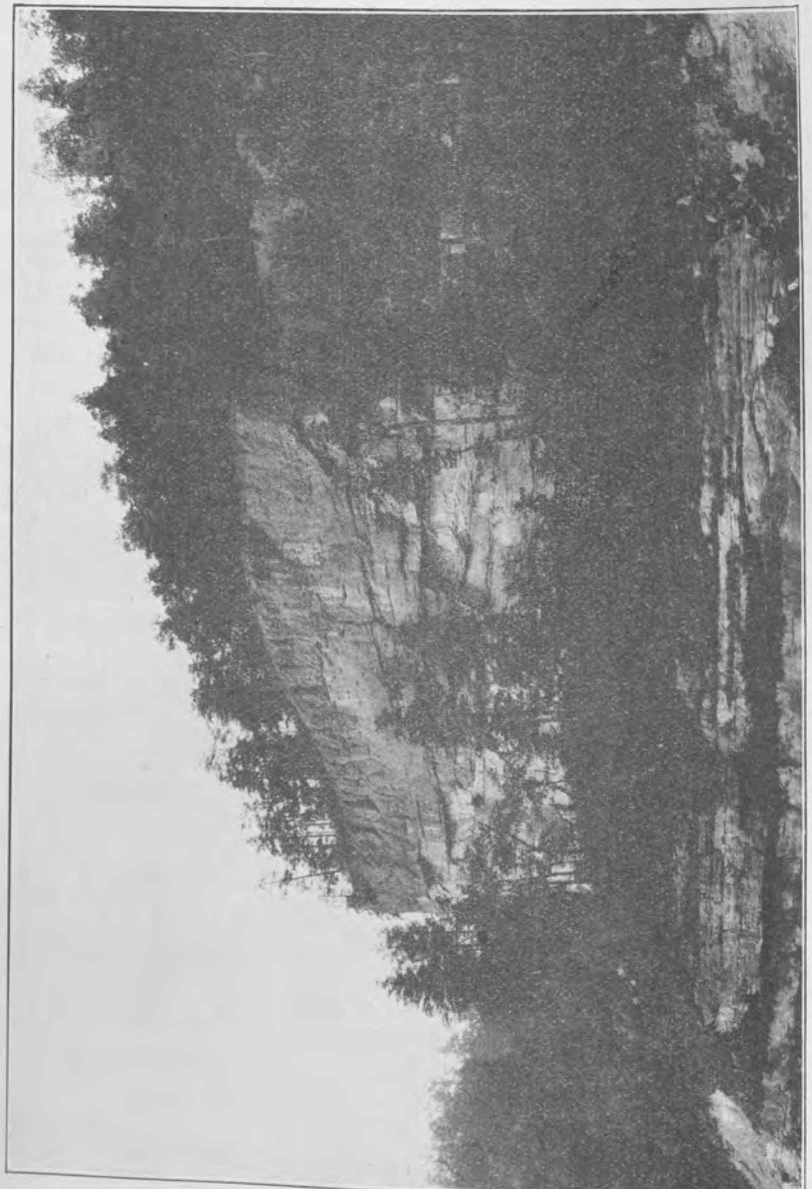

FIG. 13. LEE FORMATION IN CLEAR FORK NARROWS.

and Glenn as having similar characteristics. Since the Reynolds sandstone is nearly 200 feet above the base of the Hignite formation it is possible that a few score of feet of the basal Hignite should be included in the Wise formation. The Hignite and Bryson formations in the Cumberland Gap area contain a

FIG. 14. NORTON SANDSTONE SOUTHEAST OF COEBURN, VA.

slightly larger proportion of sandstone than the underlying Hance, Mingo and Catron formations and thus are similar to the Harlan formation of Wise County. In the Log Mountain district the Harlan formation contains a number of coal beds of workable thickness but this part of the section becomes more barren eastward, both in the Harlan region in Black Mountain and in Wise County.

Correlation With Other Areas

In the Virginia area which is continuous with the Middlesboro Basin on the east the entire thickness of coal measures from the base of the Lee formation to the highest beds of the Harlan formation which have escaped erosion has been included in the Pottsville series of the Pennsylvanian. This correlation is on the basis of fossil plant studies by David White of the United States Geological Survey, as reported by Eby and others (7-p. 62).

TENATIVE CORRELATION TABLE OF COAL BEDS IN THE MIDDLESBORO BASIN AND ADJACENT AREAS*

Wise County, Va. (Eby)	Big Black Mountain, Harlan Co., Ky.	Log Mountain, Bell Co., Ky.	Kentucky River Basin	Big Sandy River Basin
		Red Springs	Helton or Stamper	Richardson
		Hignite	Hindman	Upper Torchlight
High Splint	High Splint		Flag	Lower Torchlight
Morris	Cornett			
Pardee	Limestone	Poplar Lick	Limestone	Limestone & Thacker
Phillips	Dean or Wallins	Sandstone Parting	Fire Clay	Fire Clay
Low Splint	Low Splint	Mason, Mingo and Jellico	Amburgy	Amburgy
Taggart	Keokee or Kellioka	Bennett's Fork	Elkhorn	Elkhorn
Standiford	Harlan or "A" seam		Manchester	Shelby Gap
Kelly	Kelly			
Inboden	Imboden			
Addington				
Blair				
Lyons				
Dorchester				

*Based in the main on correlation table furnished by J. S. Hudnall of this Survey. Modified by the writer by omission of lower beds and change of emphasis on certain correlations.

In the forthcoming geologic map of Kentucky the Pottsville-Allegheny line is drawn at the top of the Wise formation and the Harlan formation is included in the Allegheny series. This has been done in accordance with the correlations of the State Survey, chiefly by Mr. James Hudnall, in the main coal field of eastern Kentucky. The present writer has made no field studies in the Kentucky or West Virginia coal fields north and east of the Middlesboro basin and has therefore no opinion of value in correlating the upper coal measure of this region.

It is impossible at the present time to make complete correlations of the coal beds of the Middlesboro basin with those of adjoining areas. An attempt is made in the accompanying table to summarize the facts so far as they are known. Of the correlations indicated therein, the Taggart-Keokee-Kellioka-Elkhorn identity is the best established, and the Mason, Mingo, and Jellico beds are probably the same and identical with this series. The Pardee-Limestone correlation is undoubted in the Black Mountain and Wise County districts. The Harlan-"A" bed is here correlated with the Standiford, but the writer believes that the interpretation of Bilips that the "A" bed is the same as the Imboden of Virginia will bear more detailed study before it is rejected. As a result of recent work north of Pine Mountain, Mr. Hudnall concludes tentatively that the High Splint and Flag beds are the same and that the Hindman and Red Springs beds are the same and above the High Splint horizon.*

Structure

General Structure of the Region

The Middlesboro basin lies on the southeast margin of the Cumberland Plateau and hence at the southeast border of essentially horizontal Pennsylvanian rocks. The striking east facing escarpment which forms the margin of the bituminous coal field in Pennsylvania, Maryland, West Virginia, Kentucky, Virginia, and Tennessee is but the surface expression of the boundary between two strongly contrasted structural provinces. Southeast of that line is a zone fifty or sixty miles in width which consists of folded and overthrust Paleozoic rocks ranging from Cambrian to Mississippian and consisting of sandstones, shales and lime-

*Hudnall, J. S. Letter dated November 1, 1925.

stones, with the latter dominant. The thrust faulting is the result of horizontal forces from the southeast and has resulted in crustal shortening of at least some tens of miles. The rocks have broken along many fault lines and outcrops of a given formation are not uncommonly duplicated several times as a result of the combined faulting and parallel folding.

FIG. 15. SHALE OF WISE FORMATION NEAR BENHAM.

West of the line mentioned above the rocks consist of nearly horizontal and but slightly disturbed Pennsylvanian sandstones and shales. These rocks are thicker at the southeast margin of present area and it seems possible that the thrust which so profoundly deformed the pre-Pennsylvanian rocks east of the Allegheny-Cumberland front was successfully resisted along this line by virtue of the superior competence of the thick mass of coal measure rocks and that the northwestward margin of thrust faulting is not far northwest of and was roughly determined by the original southeastward margin of Pennsylvanian sediments. However, little is known of the original extent of these rocks and it is not possible to state with certainty the part they played in the deformation of the Appalachian belt except that the larger part of those which remain were either too resistant or lay too far west in the direction of thrust to be greatly deformed.

For a discussion of the structural geology of areas in this region see papers by Campbell (4-pp. 30-96) and Eby (7-pp. 114-140).

Though in a broad way the structural and topographic boundary between the Appalachian valley and the Cumberland plateau is a single line sharply separating the two, there are places where, locally, the rocks of the plateau have been faulted and folded for some miles northwest of that line. A notable example of such extension of some of the features of the valley province westward into the plateau province is found in the Middlesboro basin and adjacent areas within the limits of the Cumberland Block (16). This has been described in detail elsewhere but may be characterized briefly as a mass of Pennsylvanian and underlying rocks one hundred and tweny-five miles long and averaging twenty-five miles in width which was sheared loose and thrust to the northwestward at the time of the Appalachian revolution. It is bounded on four sides by faults, the Pine Mountain and Hunter Valley thrust faults on the northwest and southeast respectively, and the Russell Fork and Jacksboro shear faults on the northeast and southwest sides. The northwestward displacement was not less than ten miles at the Jacksboro end and two miles at the Russell Fork end. The synclinal structure of the block, which will be described in greater detail below, is responsible for the principal features of the topography and areal geology of the Middlesboro basin in Kentucky and of the western end of the coal field of southwest Virginia. The upturned northwest margin of the synclinal block finds expression in the controlling barrier of Pine Mountain. The south margin of the block at the eastern end is overturned to angles of 45 degrees. Somewhat west of St. Paul, Virginia, the southern part of the block has developed an anticlinal fold which is strongly accentuated a few miles to the west as the Powell Valley anticline (1) and thence to the southwest end of the block the coal measures of its southern half have been eroded away from their uplifted position. From Norton westward to Pennington the practically vertical beds of the Lee formation in the north limb of the Powell Valley anticline form the conspicuous Stone Mountain barrier through which Big Stone and Pennington Gaps have been cut by branches of Powell River. From just west of Pennington southwestward into Tennessee the same mountain

carries the name of Cumberland Mountain and forms the Cumberland front which rises a thousand feet or more above the rolling limestone country to the southeast.

THE MIDDLESBORO SYNCLINE

That portion of the Cumberland block which now carries coal measure rocks has a synclinal structure, and is known as the Middlesboro syncline. At the northeast end this part is 25 miles

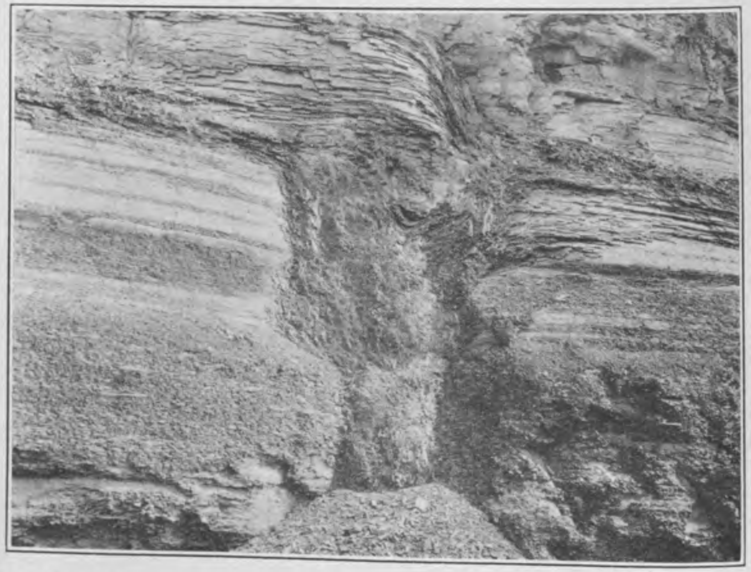

FIG. 16. WEATHERING OF SHALE NEAR HEAD OF BIG LOONEY CREEK.

wide but the rise of Powell Valley anticline westward from Dante causes the narrowing of the synclinal part to less than 15 miles, and at the extreme western end of the block it is less than ten miles wide. Because of the elevated position of the beds all the Pensylvanian rocks have been eroded from the top of the Powell Valley anticline west of Norton and from the south limb west of Big Stone Gap. All of the Middlesboro basin of Kentucky as described in this report is contained within the narrower southwestern part of the Middlesboro syncline (Figure 19). In general terms, this part consists of a relatively flat bottom with dips exceeding 100 feet to the mile in but few places and sharply

upturned northwest and southeast limbs. From Russell Fork in Virginia to the vicinity of Harlan the synclinal axis lies near the northwest margin rarely more than one or two miles from the foot of Pine Mountain, but west of Harlan it lies somewhat more nearly midway between Pine and Cumberland Mountains.

In northern Wise County about four miles east of Flat Gap the synclinal trough is interrupted by the north-south Buck Knob anticline. Immediately west of this structure the synclinal

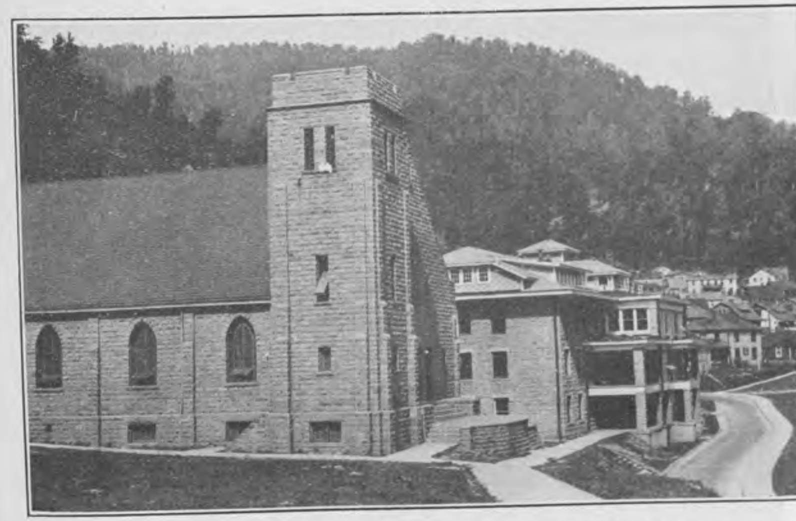

FIG. 17. BUILDINGS OF WISE SANDSTONE, LYNCH.

axis, starting from a north-south position on the Pine Mountain flank, swings in a curved course to the south and then southwest to enter Kentucky just south of Flat Gap. Following a course parallel to Pine Mountain the trough plunges a total of about 700 feet to a small inclosed basin about five miles east of Nolansburg. The trough rises slowly westward from this basin, passing over a sag about 300 feet higher just west of Harlan, through a second much shallower basin in the valley of Puckett Creek. Along the line between Pineville and Cumberland gaps there has been considerable transverse faulting with the result that sharply upturned beds of the Lee formation are exposed in Rocky Face Mountain. The writer has made no detailed study

of this area and data at hand are insufficient to warrant drawing structure contours through this zone.

West of Rocky Face the synclinal trough plunges southwestward at the rate of about 40 feet to the mile and the axis crosses the Tennessee somewhat west of Clear Fork. The productive coal areas of the Middlesboro basin are confined to the broad bottom of the syncline. Not only is the steeply dipping coal of the north and south limbs more difficult to mine, but the higher formation which bear nearly all the workable coal beds are so generally stripped off by erosion from the Pine and Cumberland Mountain flanks that the total amount of steeply dipping coal is negligible. (Figures 20, 21 22 and 23).

Coal Resources

Importance

The Middlesboro Basin constitutes one of the richest coal districts in the State of Kentucky and compares favorably in every respect with the foremost producing areas of bituminous coal in the eastern United States. There are several reasons for its prominence. The relatively high heating value of the coals of the basin is in accord with its position at the southeast margin of the bituminous field, the heating values of coals along this margin being generally about 14,000 B. T. U. and grading to 12,000 along the northwest border of the eastern Kentucky field, about 12,000 B. T. U. in the western Kentucky field, an average of 11,000 B. T. U. in Illinois, and 10,000 to 11,000 B. T. U. in Iowa. Another factor contributing to the position of the Middlesboro basin as a coal field is its inclosure between the high drainage barriers of Pine and Cumberland Mountains, which has led to the preservation of a thick series of coal bearing rocks in the high residual masses of the Log and Black Mountains. On the other hand, erosion has proceeded to a point where valleys are deeply incised in the sides of the mountains and coals of more than 2,000 feet of coal measures are accessible by horizontal drift mining with just enough dip for satisfactory drainage and economical haulage. Probably no other part of Kentucky has so extensive a series of thick and high grade coal beds favorably exposed for mining as the Middlesboro basin, and it is matched only by similar adjacent areas in Virginia.

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For a considerable period the greater remoteness of the Middlesboro coal field retarded its development but within the past 15 years the upper basin has undergone a remarkable advance in coal production until Harlan county is leading all other counties of the State by a substantial margin and in 1923 produced approximately 20 per cent of the total amount produced by the State.

Description of Coal Beds

Mode of Treatment

It has been found advisable in this report to treat the several coal beds in approximate chronological order and to carry the description under each name only over the area in which the bed has been identified with confidence. Thus, in the following sections will appear the names of beds in different districts which may later be found to be equivalent and will in later detailed reports be treated under one name. A similar grouping has been followed in making estimates of the total coal tonnage of the basin.

The very great differences which exist in the completeness of data available for the different parts of the area make it impossible to treat the descriptions with uniformity or in accordance with any rigid pre-determined scheme. In general, an attempt has been made to give briefly such available data concerning each bed as would indicate best its probable commercial value within the next few decades. Only the most important beds have been described; in each district where any considerable amount of prospecting has been done there are a number of coals which may prove to be of local value but it seems unwise in the absence of detailed areal studies to attempt the description of these local and as yet uncorrelated beds from the fragmentary data in hand.

Coal Beds in the Lee Formation

Little is known of the coal beds in the Lee formation of the Middlesboro basin and none of these are known to be of commercial importance. In adjacent areas which have been studied in detail the coal beds of the Lee formation have been found to be generally thin, much crushed, relatively impure, and lying at

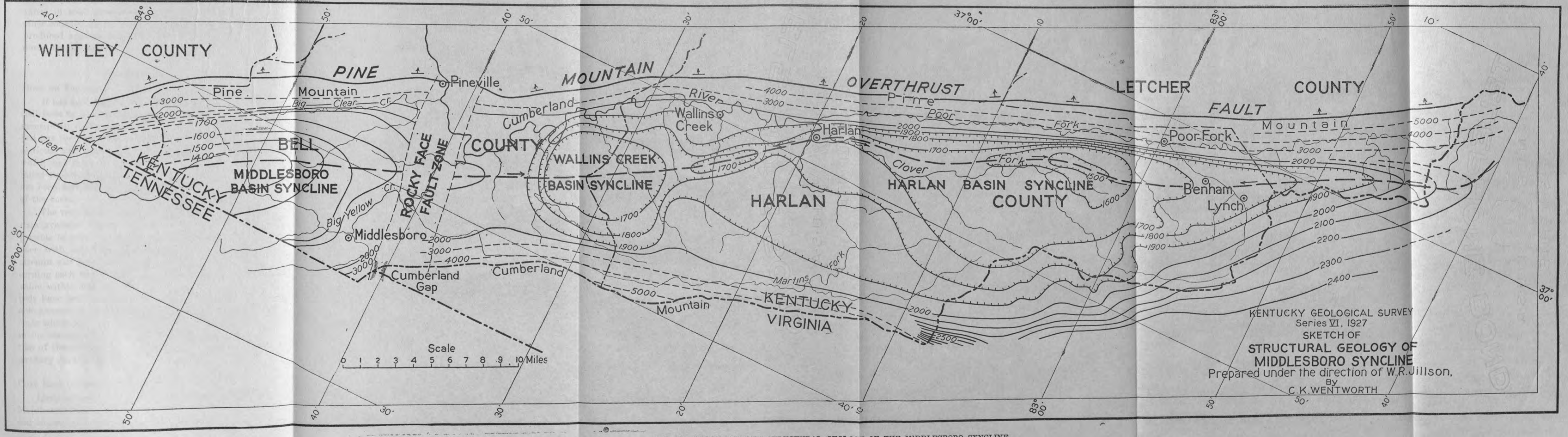

FIG. 19. RECONNAISSANCE STRUCTURAL GEOLOGY OF THE MIDDLESBORO SYNCLINE.

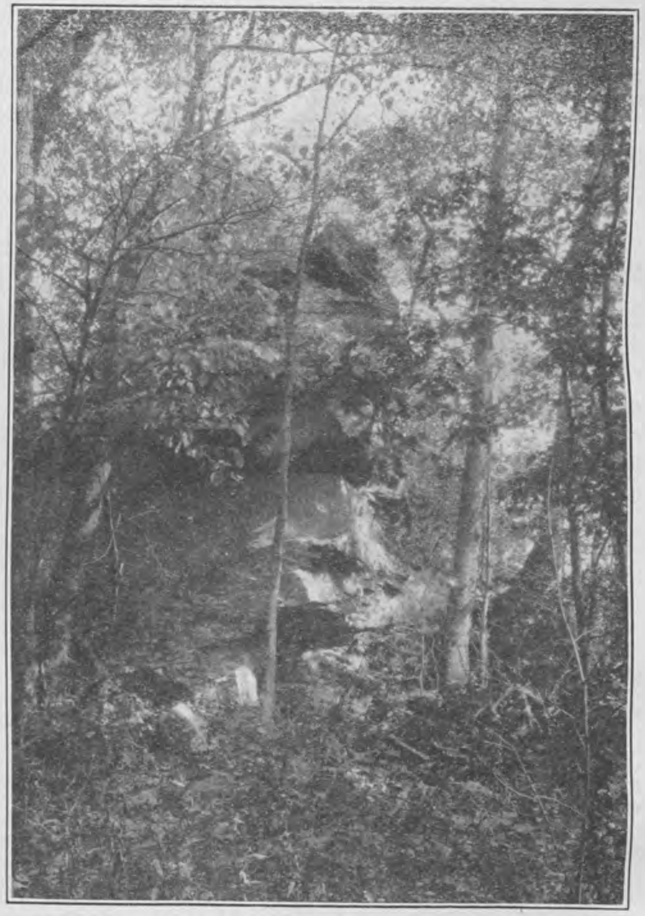

FIG. 18. HARLAN SANDSTONE, "WALL ROCK."

steeply dipping attitudes which render mining difficult even where the beds are otherwise of value (9-p. 43). A coal bed in the Lee formation has been opened in Virginia near the summit of the south face of Cumberland Mountain at Chadwell Gap, but no data are available concerning the coal or the mine at this place.

Coal Beds of the Norton Formation

If the subdivision of the lower coal measures of Middlesboro basin made by the writer in the section on stratigraphy is

correct, the Norton formation is likewise practically devoid of coal beds of commercial importance. No coal beds of value in this part of the section are described by Ashley and Glenn for the western part of the basin (1). In the adjacent parts of Virginia little is known concerning these lower coals because they are mostly below drainage but it seems probable that though a few beds may ultimately be found to have workable thickness locally the coals of the Norton formation not only go below drainage in passing westward from eastern Wise County but also for the most part thin out are reduced to little or no commercial value.

Coal Beds of the Wise Formation

Imboden Coal. The Imboden coal is not known with certainty in Kentucky. By some it is believed to correspond with the "A" bed at Lynch and Benham and hence with the Harlan bed, but this correlation can hardly be regarded as established. For the purposes of the present report, however, the Imboden bed may be regarded as extending into Kentucky under the Black Mountain mass from Flat Gap to the Pocket and either being continuous with the Harlan coal or becoming inconspicuous while the latter comes in at about the same stratigraphic position.

In the Callahan Creek basin of Virginia, adjacent to the Big Looney and Poor Fork basins of Kentucky, the Imboden coal ranges from 4 to 10 feet in thickness with numerous partings. It averages about 6 feet with an aggregate of 3 inches of parting. In the Roaring Fork basin it is 5 to 7 feet thick but thins northward with an increase in partings. A borehole at Pardee shows the Imboden and associated Kelly bed made worthless by numerous thick partings. In the South Fork of Pound River the Imboden bed averages about 3 feet in thickness (7).

Near the mouth of Frank's Creek is a coal bed described by Hodge containing about 5 feet of minable coal with several thick partings near the middle (10-p. 215). This coal bed he considers to be the equivalent of the Harlan bed but calls attention to its similarity to the Imboden south of Black Mountain. The "A" bed of Benham Spur and Looney Ridge, as prospected by d'Invilliers, ranges from 3 to 12 feet in aggregate thickness,

but shows many thick partings and probably averages between three and four feet of minable coal.*

The elevation of outcrop of the Imboden coal or of beds considered here as occupying roughly similar stratigraphic positions ranges from about 1,800 in Frank's Creek to an average of about 1,600 feet along the north face of Black Mountain west of the village of Poor Fork. The bed here dips southward at rates which increase rapidly toward Pine Mountain but which reach three or four hundred feet to the mile before it passes into the air. It is thus present over a broad area of Black Mountain and its spur ridges but it is entirely absent north of Poor Fork.

Kelly Coal. The Kelly coal ranges in Wise County from a few inches to 70 feet above the Imboden coal and has thicknesses ranging from 18 inches to 5 feet. It appears to be of little present value because of difficulty of mining it in areas where the Imboden is also present, and it has not been identified with certainty in Kentucky.

Harlan Coal. At the type locality of this bed in Little Black Mountain it is 6 feet thick and relatively free from partings (10-p. 9). In Big Black Mountain as prospected by d'Invilliers, it is split by more partings and probably averages not over 4 feet of workable coal. In the Pocket district of Virginia its equivalent, No. 3, is reported to average about 4 feet in thickness though in places it reaches 6 feet. In the Virginia area it is relatively high in sulphur but this characteristic is less apparent farther north in Kentucky. In the basin of Martins Fork the Harlan bed averages about 4 feet of workable coal, overlain by a fairly massive roof of sandstone. Its elevation is about 1,600 feet near Harlan, 1,700 feet at the head of Catron Branch, and 1,500 feet in the headwaters of Puckett Creek and near the mouth of Wallins Creek. Along the headwaters of Martins Creek on the north side of the valley the bed assumes steeper dips and reaches elevations varying from 1,500 to 2,000 feet (1-Areal Map). This coal bed is somewhat thinner in the basin of Puckett Creek, averaging probably not over 3 feet in thickness though exceptionally reaching 6 and 7 feet. In the Wallins Creek district the Harlan coal appears to thin and become unimportant. Westward toward Pineville its approximate position in the section is occupied by the Hance coal.

*Date furnished by Wisconsin Steel company, Benham, Ky.

Turner Coal. This bed is found about 200 feet below the top of the Hance formation of Ashley and Glenn, and likewise about 200 feet below the horizon of the Harlan coal. This coal has a general thickness of available coal of about 4 feet on Lane Branch of Yellow Creek and is estimated by Ashley and Glenn to contain together with the Bennett Fork coal in the Bennett Fork district a tonnage of 20,000,000. Very little detail is given by them concerning the extent of the Turner coal, and no original data is at hand for presentation here.

Taggart Coal. This coal is probably the most valuable bed in the region. It is known in the Harlan district as the Kellioka, at Benham and Lynch as the "C" bed, and its identity over the whole area from Letcher County to the Upper Puckett Creek basin is established with more certainty than that of any other coal. In the parts of Wise County, Virginia, adjacent to Letcher and eastern Harlan County, it ranges from 4 to 6 feet thick, averaging perhaps 5 feet, and is a very high grade coal of remarkable freedom from partings. It is probably somewhat thinner to the northward in the basin of the south fork of Pound River and at one place carries a parting several inches thick near the middle of about 5 feet of minable coal. Prospecting by d'Invilliers and mining operations at Benham and Lynch show generally 5 to 6 feet of clean coal in the northern and eastern parts of the Big Looney Creek basin and adjacent parts of Black Mountain to the northeast. From Lynch southwestward into the Cloverlick basin a parting splits the bed and at prospects west of the mouth of Cloverlick Creek it consists of two 2-foot benches of coal separated by about 30 feet of shale.

The Taggart bed averages 3½ feet thick in Lee County, Va., being somewhat thicker at the east.

Along the north face of Black Mountain from Cloverlick Creek to Harlan the Taggart bed under the name of Kellioka consists of a workable bench of coal about 3½ to 4 feet thick with several thinner coals and partings above. South of Harlan and in much of the Martins Fork district the Kellioka coal is much split by partings which vary greatly from place to place but may be considered generally to carry 3 to 4 feet of minable

coal. In the Upper Puckett Creek basin this coal probably carries about 3 feet of workable coal though the total section including several partings is 6 to 7 feet thick in places. In the Lower Puckett basin the bed is much thinner and may not be present at all in parts of the area. Farther west in the Log Mountain district the Taggart-Kellioka coal is thought to be represented by the bed known as Mason, Mingo and Jellico.

The Taggart coal lies at elevations ranging from 2,300 feet under the highest points of Black Mountain southeast of Lynch to about 1,500 feet in the basin of Clover Fork east of Nolansburg. It thus underlies a large part of the area of the Middlesboro basin east of Wallins Creek, though in the same district it is eroded away from somewhat larger areas than the lower Imboden or Harlan beds.

Mingo Coal. The Mingo coal is most prominent in the Bennett Fork and Stony Fork-Clear Creek districts of the Log Mountains. In Bennett Fork basin it carries from 4 to 5 feet of workable coal split into two or more benches by clay partings which range from a few inches to 3 or 4 feet in thickness. According to Ashley and Glenn this coal is of workable thickness in a limited area on the north side of the Log Mountains in the basin of Clear Creek but of very doubtful value in the intermediate area in the basin of Stony Fork (1). Data given by Crandall and Sullivan supplement this view and this bed is reported to be workable in parts of the Yellow Creek basin east of Rocky Face, but no detailed information as to its character is available.

Creech Coal. The Creech coal outcrops at elevations of about 2,000 feet in the lower basin of Puckett's Creek and adjacent parts of the basin of Brownies Creek. It has a thickness in most of the Jackson Mountain area of about 5 feet and thins rapidly toward the southeast as far as is shown by data available to the writer.

Low Splint Coal. This bed averages about 3 feet thick in parts of Wise County adjacent to Kentucky and becomes thicker, reaching 5 feet in Lee County. It is commonly from 200 to 250 feet above the Taggart coal and is reported by Hodge to be 3 to 4½ feet thick throughout much of the Little Black Mountain area. It is not known to be of workable thickness in Big Black

FIG. 20. EAST BLUFF OF PINEVILLE GAP.

Mountain west of Poor Fork village. It contains a small amount of splint coal but the name seems hardly justified except as it has been fixed by custom.

Sandstone Parting Coal. This coal is present with workable thickness throughout most of the Log Mountain district at elevations approximating 2,000 feet. It is characterized by a sandstone parting which appears not to be constant at any one horizon but occurs in some places near the top and at other places near the base of the bed. In the Bennett Fork basin the Sandstone Parting coal has a workable thickness of 3 to 4 feet and becomes thinner to the north, being reduced to an average of about 2½ to 3 feet in the Clear Creek basin.

Phillips Coal. The Phillips coal is about 2 feet thick throughout most of the Black Mountain district of Wise County but apparently thickens westward and has an average thickness of 4 feet in the Pocket district of Lee County. Under the name of Dean coal this bed is described by Hodge and reported to contain 3 to 3½ feet of coal in parts of Little Black Mountain. It is believed to be the same bed as the Wallins Creek described elsewhere in this report.

Poplar Lick Coal. This bed lies at elevations of 2,200 to 2,400 feet in the Log Mountain district and is one of the most important beds in the section. It is about four feet thick in the basin of Stony Fork and slightly thinner in the basin of Bennett Fork. In the basin of Clear Creek this bed contains from 4 to 4½ feet of workble coal in two benches separated generally by a single parting which is usually less than 12 inches thick but in a few places reaches 4 feet in thickness.

Wallins Creek Coal. This bed is believed to be the equivalent of the Poplar Lick coal of the Log Mountain district. It is found at elevations ranging from about 2,400 feet in the vicinity of Harlan to nearly 3,000 feet on the north side of the upper basin of Martin's Fork. It has a workable thickness of over 5 feet in the lower basin of Puckett Creek near the western limit of its preservation. In the upper basin of Puckett Creek it has an average minable thickness of 6 to 7 feet with about a foot more below a fireclay parting several inches thick. In the vicinity of Harlan the bed probably contains 3 to 3½ feet of

coal in Little Black Mountain and is not known to have a workable thickness in Big Black Mountain.

Pardee Coal. In northwestern and western Wise County, Virginia, and adjacent parts of Kentucky, the Pardee coal bed lies at elevations from 2,800 to 3,100 feet. It reaches its maximum thickness in the Roaring Fork basin in Virginia where it is 9 to 11 feet thick and carries but slight partings. West of this

FIG. 21. LEE CONGLOMERATE, NEAR PUTNEY, HARLAN CO.

locality it is split by partings which are very variable. In Lee County this bed averages 6 feet in thickness and seems likely to attract development in spite of its elevation and small area. According to Hodge this bed is the equivalent of the Smith coal, which has a thickness of 11 to 13 feet on Gray's Knob. Prospecting reported by Hodge indicates that this bed is present with thicknesses of 5 to 10 feet along upper Poor Fork in Letcher County and with thicknesses varying greatly but ranging from 3 to 6 feet throughout most of the Black Mountain district from Lynch to Harlan. In general the bed appears to be extremely variable, much split by partings but locally becoming thick and practically free from partings as at Pardee in Virginia.

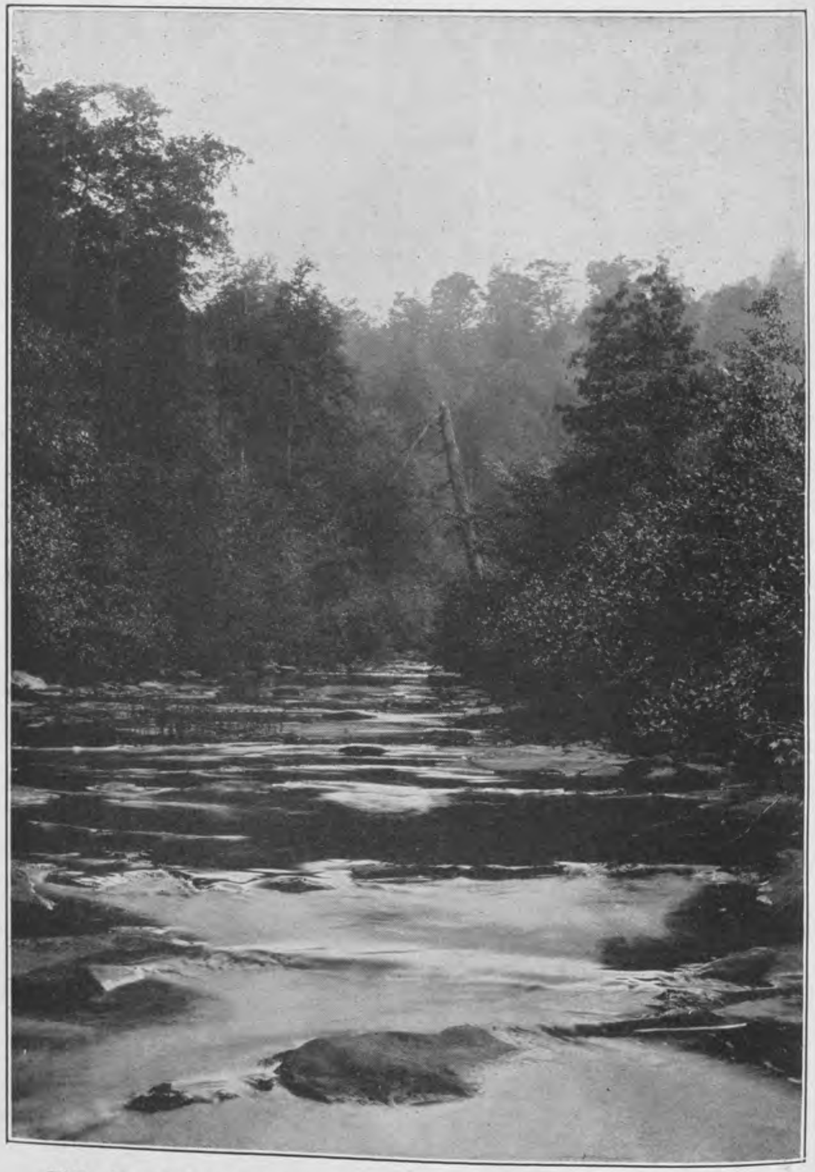

FIG. 22. CHANNEL OF CLEAR CREEK AND STRIKE RIFFLES.

Klondike Coal. The Klondike coal lies from 30 to 80 feet above the Poplar Lick coal in the Log Mountain district. In places the bed is considerably split by partings but it may be regarded as containing an average of 3 feet of workable coal in the Clear Creek basin and about 4 feet in the Bennett Fork and Stony Fork basins where the partings are not so conspicuous.

Smith coal. This bed is reported to have a thickness of 10 or 11 feet of workable coal at Grays Knob and at another locality near the head of Pucket Creek. Similar thicknesses are not found in adjacent areas at this horizon, about 100 feet above the Wallins Creek coal, so far as known to the writer and the exceptional thicknesses mentioned appear to be of very local occurrence. It is thought that they represent local thickening of a coal having an average thickness of 3 or 4 feet. The Smith coal is generally considered to be the equivalent of the Klondike coal of the Log Mountain district.

Morris Coal. This bed, which is probably the equivalent of the Cornett of Kentucky, has thicknesses of 3 to 5 feet along the State line from the Pocket in Lee County to Roda in Wise County. Similar thicknesses are reported by Hodge in Big and Little Black Mountains east of Harlan. The Morris coal lies an average distance of 350 feet above the Pardee coal and 50 to 75 feet below the High Splint coal. Elevations range from nearly 3,400 feet at Roda to less than 2,800 feet near Harlan. The bed is not known to be present east of Roda or west of Harlan.

Hignite Coal. The Lower Hignite coal lies at elevations of 2,300 to 2,600 feet in the Log Mountain district. It has an average thickness of about 5 feet in the Bennett Fork basin and a little over 3 feet in the Stony Fork and Clear Creek basins. The Upper Hignite bed is variable and much split by partings. It is not known to be workable in the Bennett Fork basin but probably will ultimately yield 2 to 3 feet of coal over at least part of the Stony Fork and Clear Creek basins.

High Splint Coal. This coal is found at elevations ranging from about 3,800 feet near the head of Big Looney Creek to about 2,700 feet in the Black Mountain summit east of Nolansburg. In the Black Mountain summit adjacent to Wise County, Virginia, the High Splint bed consists of 4 to 7 feet of clean

coal nearly free from partings, of which nearly the whole, especially toward the base, is splint coal. In the Black Mountain spurs which extend into Kentucky between Poor Fork and Clover Fork the High Splint bed as prospected by d'Invilliers is split into three beds with a range between the upper and lower of 40 to 60 feet. Of these beds the uppermost is the most valuable, averaging 4 to 5 feet of minable coal nearly free from partings. Each of the other beds averages from 2 to 3 feet of clean coal over the rather restricted areas lying above 2,800 to 3,000 feet. Along the Virginia-Kentucky line in Lee County the High Splint coal is 4 to 5 feet thick, free from partings and mainly splint coal. According to Hodge this bed averages nearly 6 feet in thickness in all the summit area between Clover Fork and Big Looney Creek and becomes thinner, perhaps not over 3 feet thick on Black Mountain, in much of Letcher County.

This bed is not known to be present west of Harlan though detailed work may establish the identity of this bed with one of the higher beds of the Log Mountain district. The High Splint coal is found over a total area of less than 50 square miles and thus has an existing tonnage of far less than any other of the important beds in the region, but its high quality and rather uniform thickness of 5 or 6 feet make it of great ultimate value.

Red Spring Coal. This bed, which underlies small areas at the summit of the Log Mountain, has a thickness of 5 to 7 feet in the Bennett Fork basin and averages about 4 feet in the Stony Fork and Clear Creek basins. It is a high grade coal but carries a relatively small total tonnage because of the small area under which it is preserved.

Quality of Coal

In an accompanying table are given the results of analyses of a large number of samples of coal collected from coal beds of the Middlesboro basin and adjoining areas in Virginia. These have been averaged for the principal beds in another table which will be the basis of a brief discussion of the quality and value of the coal of the Middlesboro Basin compared to other producing districts.

As is now generally known, coal is produced by the slow alteration and devolatilization of great masses of plant debris,

PHOTOGRAPH BY W. R. JILLSON

FIG. 23. MOUNTAIN UPLANDS AND LOWLANDS.

This view on Catron Creek of Martin's Fork is typical of the topography of this part of the Cumberland River basin in Harlan County, Ky.

FIG. 24. KENTUCKY COAL PRODUCED IN HARLAN COUNTY.

such as stems, leaves, spores, etc., which have accumulated and been buried by other sedimentary materials like sand, clay or mud. The principal factors in determining the different kinds of coal available to man are the nature of the original plant material and accompanying mineral impurities (the chief source of ash) and the stage reached by the coal in "Coalification" process. The first factor determines the purity of the coal and results in its classification as a high or low *grade* coal. The second factor determines its *rank*. In the process of alteration, the original vegetal matter passes through a number of different stages during which it would be progressively known as *lignite, subbituminous coal, bituminous coal, semibituminous coal, semi-anthracite coal, and anthracite coal*, and thence in extreme cases passing into graphite. Thus lignite is a low rank coal; whereas anthracite is a high rank coal. Either may be of high or low grade (3-pp. 3-10).

The coal of the Middlesboro basin is a high grade bituminous coal having a heating value ranging in different beds from 13,000 to 14,500 British Thermal Units. It is a hard, blocky coal which can be and is largely delivered to the railroads in large lumps. It thus stands shipping well and is adapted to steam production, export trade and domestic use. This coal is comparatively low in moisture and ash and exceptionally low in sulphur.

For most purposes the value of a coal is most easily measured by its heating value and in this respect the Middlesboro coals are second only to a few districts which are situated close to the southeast border of the eastern bituminous coal field, notable among which is the famous Pocahontas field of Tazewell County, Virginia. The Middlesboro coals have an average heating value almost identical with that of coals of the Pittsburg district and higher than those of any of the fields of Ohio, Indiana, Illinois, western Kentucky and considerable part of the eastern Kentucky field.

The Taggart coal, which is mined in such large quantities at Benham and Lynch and a number of localities in Wise County, Virginia, has the highest heating value and lowest sulphur content of any in the field, so far as available analyses show, and is surpassed in low ash content only by the Mason,

which may prove to be the same bed. Analyses of samples taken at Roda, Virginia, placed the Taggart in a position distinctly superior to other coals in Wise County and nearly equal to that of the Pocahontas coal. Analyses of this bed in the Kentucky area indicate a slightly lower heating value and slightly higher ash, but the difference is not sufficient to displace this coal as an exceptionally high grade coal. The Upper Hance, Imboden, Harlan, Creech, Wallins and Pardee beds follow closely behind the Taggart and Mason in heating value and other characteristics.

Practically all the Middlesboro Basin coals are adapted to the production of high grade coke. Detailed tests of coals collected in and near Wise County, Virginia, have been made with reference to use as a source of producer gas, for steam producetion, and with regard to fusibility of ash and have been described and interpreted by Eby (7-pp. 530-544). Conclusions reached for the Wise County coals are applicable in general to practically all the coal of the Midlesboro Basin.

TABLE OF AVERAGES OF ANALYSES OF IMPORTANT COAL BEDS IN AND NEAR THE MIDDLESBORO BASIN.

Coal Bed	No. of Analyses	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value in B. T. U.
Imboden*	15	2.4	34.3	57.8	5.5	.75	13960
Harlan	86	3.4	36.6	56.1	3.9	.84	13990
Upper Hance	5	2.3	38.0	55.1	4.6	1.57	14100
Taggart	11	2.8	37.2	56.8	3.1	.61	14260
Mason	15	3.2	37.5	55.6	2.4	1.09	14040
Creech	8	2.4	37.2	55.9	4.4	.82	13960
Sandstone Parting	5	3.0	35.5	54.8	6.7	1.10	13460
Wallins	12	3.1	38.6	54.2	4.0	.83	13730
Poplar Lick	15	3.1	37.6	51.2	8.1	2.14	13210
Smith	7	4.1	34.8	53.1	8.0	.96	12900
Pardee*	11	2.8	35.3	55.8	6.1	.99	13770
Hignite	10	4.5	36.5	54.6	4.5	.89	13560
Sterling	5	2.3	37.1	51.1	9.5	1.06	13120
Average		3.0	36.6	54.8	5.4	1.05	13700

*Averages for these beds in and near Wise County, Virginia (7-p. 531).

Availability of the Coal

Conditions in the Middlesboro basin are especially favorable for economical mining. In part these conditions are shared by other parts of the coal field of eastern Kentucky, but in part they are peculiar to the area covered by this report. The Black Mountain area, with its great mountain spurs extending west

FIG. 25. TOWN AND STORAGE TRACKS, LYNCH, KY.

and north and drained by streams flowing into Poor and Clover Forks of Cumberland River, is underlain by enormous quantities of coal which in general dips west and north at angles sufficient to favor convenient drainage and haulage. Areas of coal in unbroken patches are large enough to invite the development of large and efficiently organized operations. There is practically no gas in mines in this area. The large number of productive beds tends likewise to favor permanent development and to stabilize the industry for a long period of years. With the building of the Louisville and Nashville Railroad line from Pineville to Harlan and thence to Benham and Lynch, with its numerous spur tracks in the Harlan district, was initiated a tremendous expansion of coal production which is still in progress and which is well indicated in the increase of production in Harlan County in recent years.

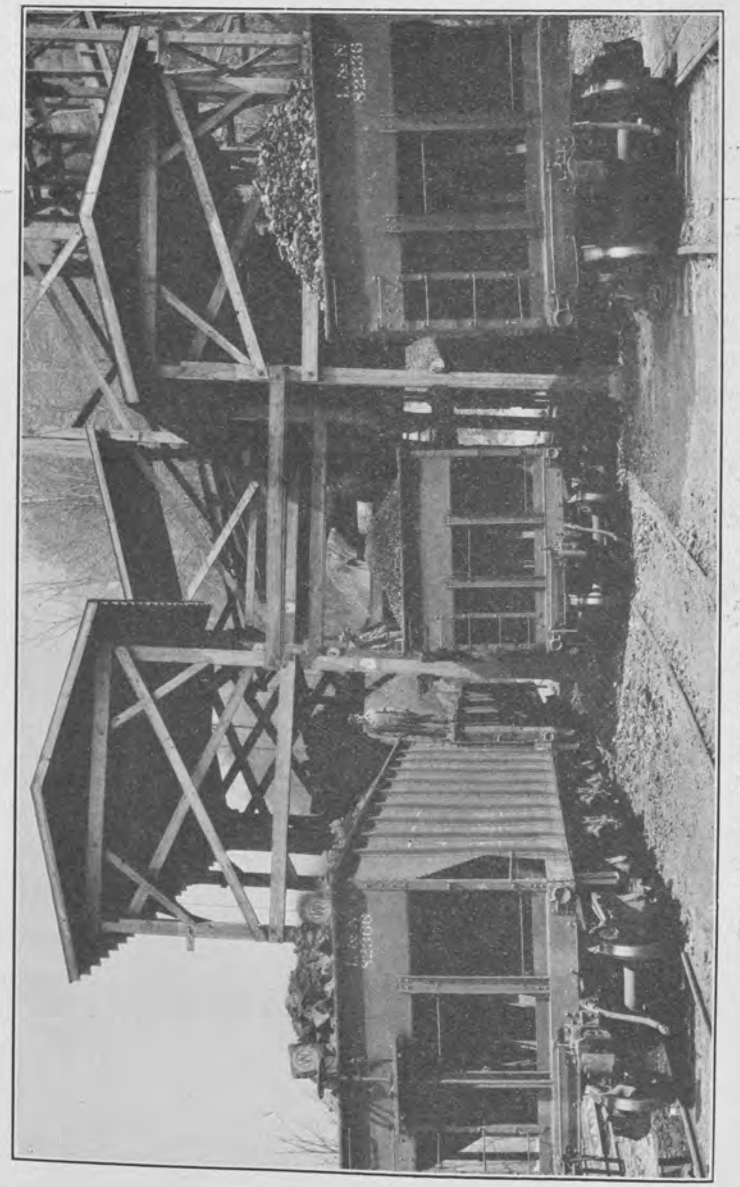

FIG. 26. A THREE TRACK TIPPLE IN HARLAND COUNTY.

Estimate of Original Coal Resources

The estimate presented herewith is substantially an estimate of existing reserves, since the amount of coal mined in this field to date is well under a hundred million tons and therefore scarcely two per cent of the total estimated as originally present. Available data are entirely inadequate to justify a detailed estimate bed by bed, measuring areas by planimeter and considering areas of different thicknesses for each bed. This can only be accomplished when proposed detailed surveys of both Harlan and Bell counties have been completed and outcrop maps and thousand of measured and reported bed sections are available.

In making the present rough estimate an effort was made for each bed to reach a judgment as to its workable extent and average thickness from such fragmentary information as was in hand. The area was estimated by reference to a grating with one mile squares and the tonnage computed on the basis of 1,150,000 tons per foot of thickness per square mile. The figures thus derived for total tonnage are certainly minimum amounts, probably for below actual amounts ultimately available. There are several reasons for this, as follows: Data for many of the beds is very incomplete, and the policy was followed of estimating only areas of practically proven thickness and freedom from partings. Only those beds of well established worth have been included in this estimate. Though the amount of coal in the Lee and Norton formations is certainly small compared to that in the Wise formation, nevertheless there will be found in these formations when prospecting is complete beds of coal capable ultimately of yielding many million, and perhaps some hundreds of million tons of coal. None of these were considered in the table which follows. In the beds considered both the areas and thicknesses were kept low in all cases of doubt.

Though the figures given are subject to much revision when detailed studies have been made and are not at all of comparable validity to those worked out for adjacent areas in Virginia in recent years, they are sufficiently near the truth to show the enormous quantities of coal available in this field and to indicate what a tremendous factor the coal industry is and will con-

tinue to be in considering every economic and social problem in this region.

TABLE OF ESTIMATED COAL TONNAGES*
MIDDLESBORO BASIN, KENTUCKY

Name of Bed	Area Taken	Average Thickness	Mainly East of Pineville	Mainly West of Pineville
	Square Miles	Feet	Millions of Tons	
Red Spring	3	5		17
High Splint	44	5½	279	
Hignite	13	4		60
Morris	40	3	138	
Smith	10	4	46	
Klondike	24	3½		97
Pardee	60	5	345	
Wallins Creek	20	4½	104	
Poplar Lick	25	4		115
Phillips	80	3	276	
Sandstone Parting	25	3		86
Low Splint	90	3½	362	
Creech	6	4½	31	
Mingo	30	3		104
Taggart	208	3¾	897	
Turner and Bennet Fork	8	3		28
Harlan	145	4½	750	
Cranes Creek and Puckett	6	3	21	
Kelly	50	2½	144	
Imboden	90	4	414	
			3,807	507
				3,807
		Grand total		4,314

*Based on a tonnage of 1,150,000 tons for each square mile of 1 foot thickness and figures rounded to nearest million tons.

Perhaps one of the most striking features of the estimate shown is the great preponderance of tonnage in the areas east of Pineville over the Log Mountain district. This is due largely to the much greater area of the former area, but may in part be due to the incompleteness of the writer's information concerning the Log Mountain coals. Another impressive feature is the tremendous tonnage contained in the Taggart, Harlan and Imboden beds. These amounts are greatly in excess of amounts in the

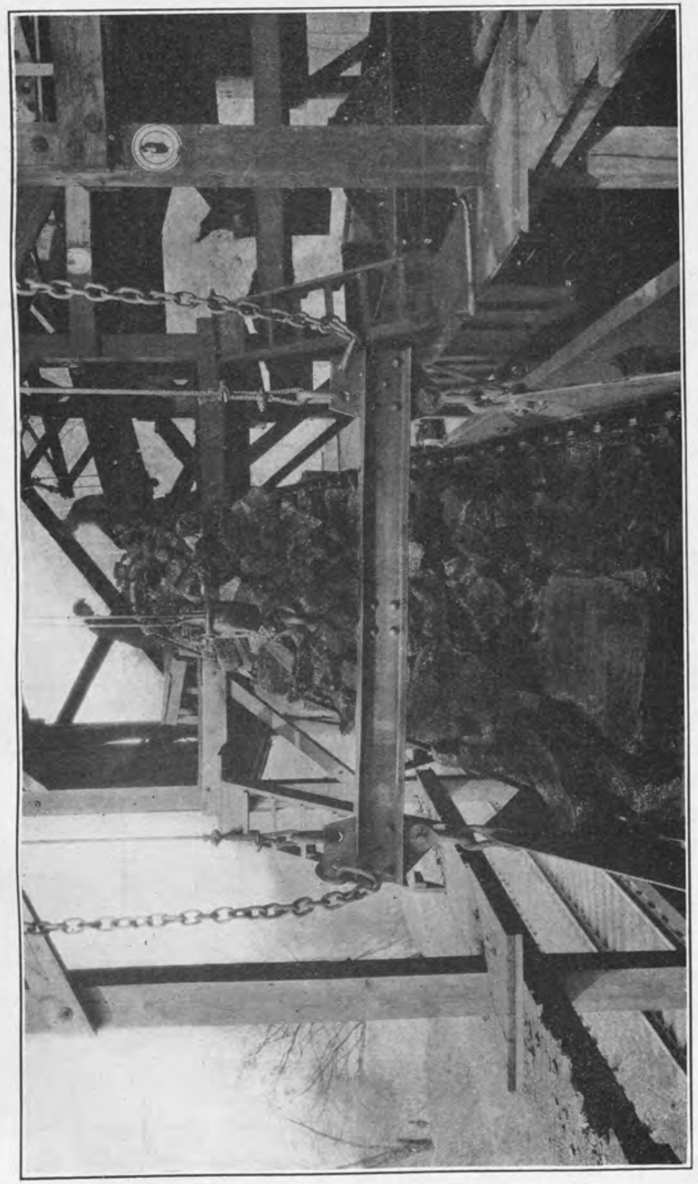

FIG. 27. NEAR VIEW OF LOADING CONVEYOR.

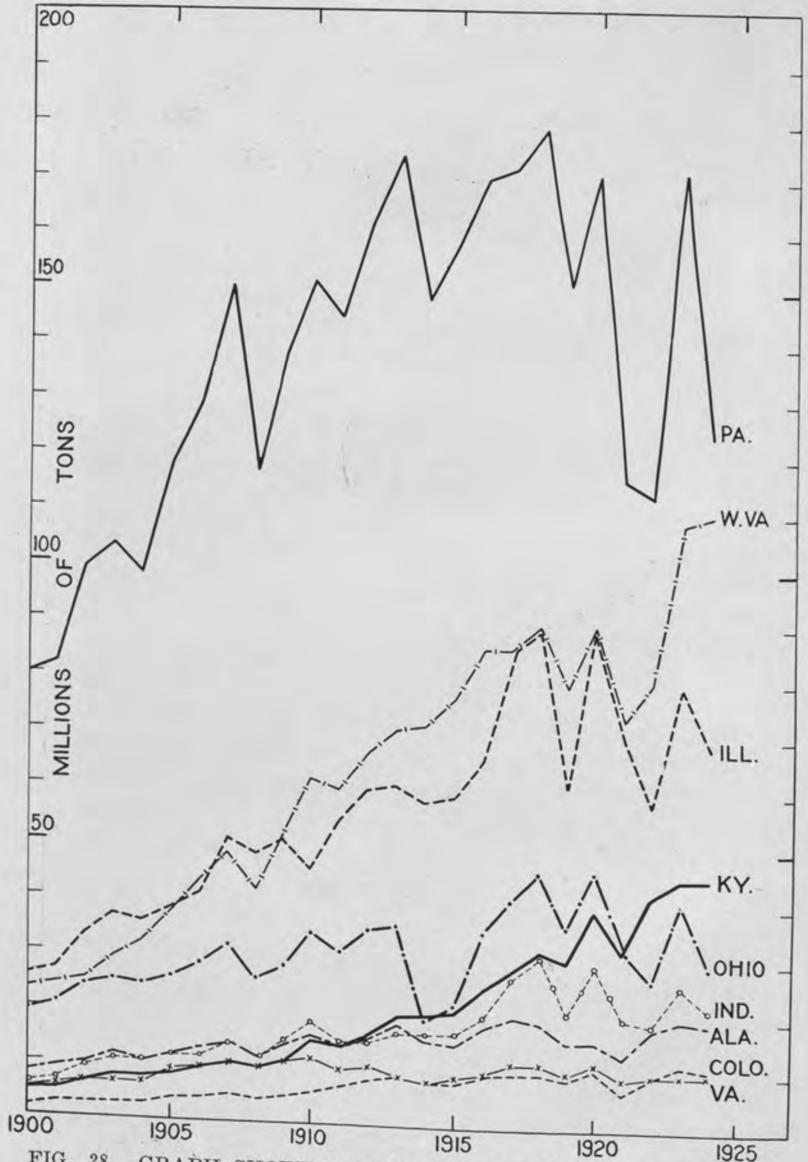

FIG. 28. GRAPH SHOWING PRODUCTION RANK OF KENTUCKY AMONG COAL PRODUCING STATES.

same beds in Wise and Lee counties and are explained by the fact that far larger areas of the great Black Mountain mass lie in Kentucky than in Virginia. In proportion to total coal area the relative coal resources of the Middlesboro basin and of the two adjacent Virginia counties are shown in the following table:

Field	Coal Bearing Area (Sq. Mi.)	Coal Resources (Millions of Tons)	Million of Tons Per Sq. Mi.
Wise County	451	5,778	12.8
Lee County	77.8	1,953	25.1
Middlesboro Basin	727.3	4,314	5.9

COAL PRODUCTION

General Statement

The annual coal production of the Middlesboro basin at present is about eleven million tons, or approximately 25 per cent of the total state output. The following table summarizes some of the salient facts of this industry.

Methods of Mining

Methods of mining in the Middlesboro basin are those common throughout the coal field of eastern Kentucky. These have been described in a recent report issued by this survey and will not be described in detail here. Substantially all the coal mined in this area is from drift mines, all but an almost negligible fraction is undercut by electrically driven cutting machines, a similar bulk of the total output is hauled to the tipple by electric locomotives and a large part of the total is prepared and loaded through thoroughly modern and in many cases all steel and concrete tipples. Indeed, the tipple of the U. S. Coal and Coke Company is said to be the largest and most efficiently arranged tipple in the world and has made daily loading records approaching twenty thousand tons. With the development and increasing importance of the industry has come increasing recognition that higher first costs in such matters as tipple construction, heavier rails and mine cars, more ample means of lighting and ventilating mines, as well as attention to human welfare both

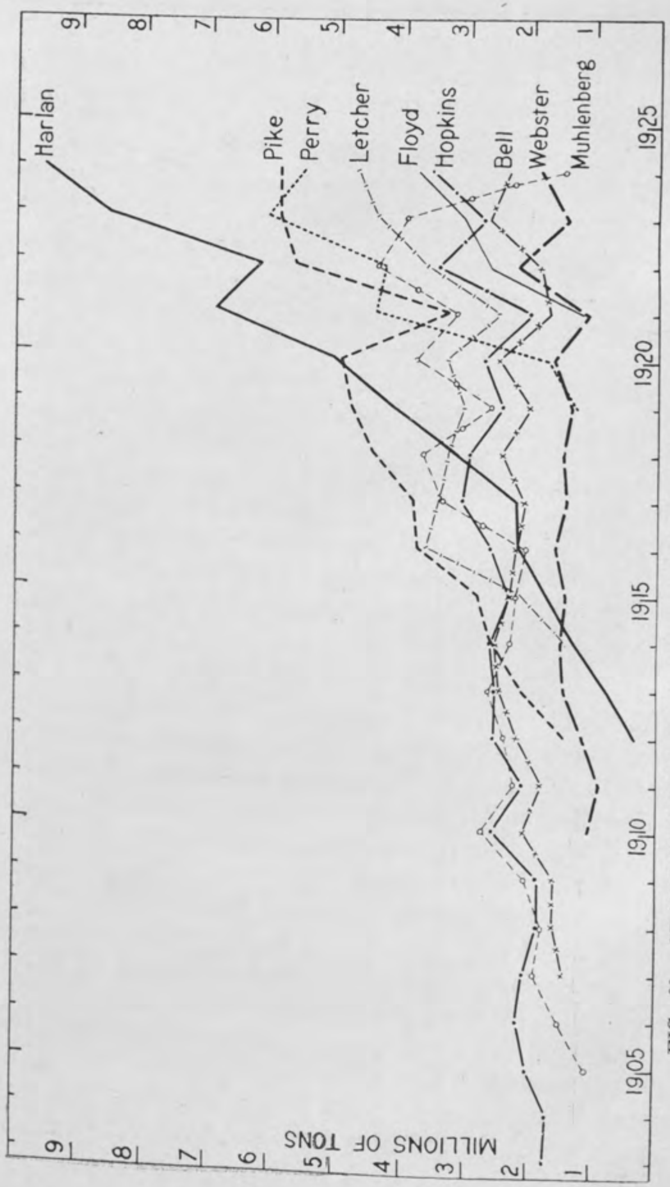

FIG. 29. GRAPH SHOWING COAL PRODUCTION RANK OF KENTUCKY COUNTIES.

inside and outside the mines, mean ultimate lower costs of operation and hence lead to economical production of coal in the long run.

Living Conditions

In the early days of coal mining in the mountainous country of the Allegheny and Cumberland Plateaus of West Virginia, Kentucky and Virginia, the towns which sprung up around the mines were ill planned and left to grow pretty much by themselves. Under the initially unfavorable conditions imposed by the narrow valleys and heavily timbered steep mountain slopes, many of these towns were unattractive and dirty and unsanitary conditions prevailed. Though unfortunately such conditions still exist in some parts of the coal mining area, there have been vigorous and largely successful efforts on the part of many of the larger operators to build carefully planned towns with such attention to sanitation, to providing of schools, churches, recreational centers, and good roads as establish many of the mining towns among the most modern and highly organized industrial towns in the world. Notable achievements in this direction may be seen in practical operation in the U. S. Coal and Coke Company town and plant at Lynch, on Big Looney Creek.

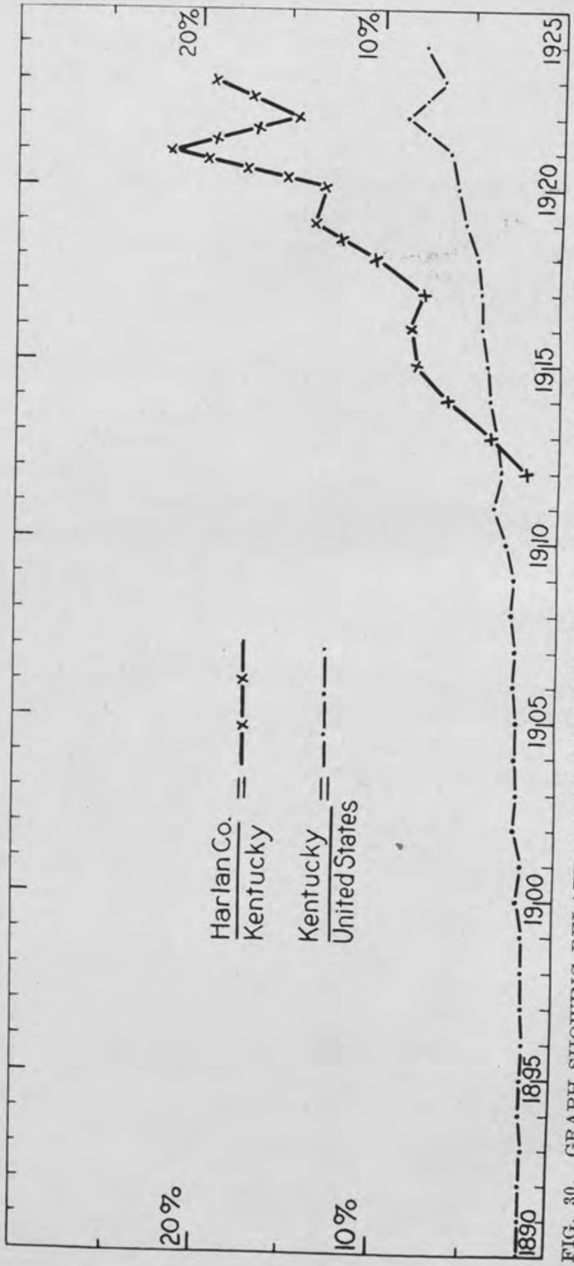

FIG. 30. GRAPH SHOWING RELATIVE COAL PRODUCTION OF THE UNITED STATES, KENTUCKY AND HARLAN COUNTY.

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APPENDIX A.

TABLE SHOWING COAL OPERATORS IN THE MIDDLESBORO BASIN*

Mines in Bell County.

Name	P. O.	R. R.	Equipment	Coal Bed	Annual Output (Tons)
Chenoa-Hignite Coal Co.	Chenoa	L. & N.	Electric	Turner	59,996
Log Mountain Coal Co. (B. F. Mine)	Bosworth	L. & N.	Electric	Mason	34.608
Log Mountain Coal Co.	Harrison	L. & N.	Electric	Mason	12,010
Fidelity Coal Co.	Meldrum	L. & N.	Electric	Raven	6,102
Victor Coal Mining Co.	Middlesboro	L. & N.	Pick	Straight Creek	33,734
Low Ash Mining Co.	Shamrock	L. & N.	Pick	Excelsior	35,955
Gravity Coal Co.	Bosworth	L. & N.	Pick	Straight Creek	4,132
Bellman Coal Co.	Bosworth	L. & N.	Electric	Turner	68,922
Atlas Coal Mining Co.	Ralston	L. & N.	Electric	Dean	41,167
Pinnacle Coal Mining Co.	Ralston	L. & N.	Pick	Jellico	27,589
Crystal Coal Co.	Logmont	L. & N.	Pick	Star Creek	8,624
W. E. Gunn & Co.	Middlesboro	L. & N.		Lower Hignite	120,000
Log Mountain Coal Co.	Davisburg	L. & N.	Electric	Mason	5,054
Hawley Coal Co.	Middlesboro	L. & N.	Pick	Jack Rock	9,500
Clover Leaf Coal Co.	Middlesboro	L. & N.	Pick	Sandstone	9,561
Long Branch Coal Co.	Shamrock	L. & N.	Pick	Straight Creek	45,000
Monarch C. & C. Co.	Middlesboro	L. & N.	Electric	Hignite	54,366
Climax Coal Co.	Shamrock	L. & N.	Electric	Sterling	101,247
Congress Coal Mining Co.	Shamrock	L. & N.	Pick	Turner	10,507
Southern Mining Co.	Balkin	L. & N.	Electric	Creech	155,468
Southern Mining Co.	Colmar	L. & N.	Electric	Creech	91,482
Harlin-Wallins Coal Corp.	Oleika	L. & N.	Electric	Mason	45,858
Varilla Coal Corp.	Varilla	L. & N.		Hance	75,000
Long Ridge Coal Co.	Hulen	L. & N.	Electric	Jellico	25,633
Kentucky Cardinal Coal Co.	Cardinal	L. & N.	Electric	Harlan	90,399
Hulen Coal Co.	Hulen	L. & N.			45,000
Brooking Coal Co.	Hulen	L. & N.	Pick	Harlan	5,837
Blacksnake Coal Co.	Hulen	L. & N.	Pick	Jellico	15,000
Virginia-Harlan Coal Corp.	Balkin	L. & N.	Electric	Harlan	74,501
Layman Calloway Coal Co.	Hulen	L. & N.	Pick	Mason	38,274
Clear Fork C. & C. Co.	Middlesboro	L. & N.		Mingo	240,000
American Fuel Co.	Wallsend	L. & N.	Electric	Jellico	47,185

*Data compiled from 1923 report of the State Mine Inspector (2) and from a Directory of Coal Mines in Eastern Kentucky by P. M. Sherwin (13). Includes all operators as active by Sherwin in April, 1925.

TABLE SHOWING COAL OPERATORS IN THE MIDDLESBORO BASIN—Continued.
Mines in Harlan County.

Name	P. O.	R. R.	Equipment	Coal Bed	Annual Output (Tons)
Harlin-Wallins Coal Corp.	Molus	L. & N.		Harlan	120,000
Harlin-Wallins Coal Corp.	Wallins Creek	L. & N.	Electric	Wallins	300,000
Harlin-Wallins Coal Corp.	Harlan	L. & N.	Electric	Harlan	300,000
Black Star Coal Co.	Path Fork	L. & N.	Electric	Harlan	156,781
Creech Coal Co.	Twila	L. & N.	Electric	Wallins	187,124
Utilities Coal Corp.	Wallins Creek	L. & N.		Wallins	360,000
Banner Fork Coal Corp.	Harlan	L. & N.	Electric	Wallins	361,083
White Star Coal Co.	White Star	L. & N.	Electric	Harlan	160,783
Perkins Harlan Coal Co.	Harlan	L. & N.	Electric	Harlan	112,072
Bowling Coal Mining Co.	Bardo	L. & N.	Electric	Harlan	79,660
Harlan Fuel Co.	Harlan	L. & N.	Electric	Harlan	84,000
McComb Coal Co.	Elcomb	L. & N.	Electric	Harlan	48,814
R. C. Tway Coal Co.	Harlan	L. & N.	Electric	Harlan	135,487
Shawnee Gas Coal Co.	Harlan	L. & N.	Electric	Harlan	21,408
Wilson Berger Coal Co.	Grays Knob	L. & N.	Electric	Smith	197,921
Harlan Superior Coal Co.	Harlan	L. & N.	Pick	Harlan	20,338
Crown Coal Co.	Chevrolet	L. & N.	Electric	Harlan	162,313
Mary Helen Coal Corp.	Coal Good	L. & N.	Electric	Harlan	238,500
Lena Rue Coal Co.	Lenarue	L. & N.	Electric	Harlan	62,440
Ellis Knob Coal Co.	Cawood	L. & N.	Electric	Harlan	115,197
Three Point Coal Co.	Lenarue	L. & N.	Electric	Harlan	50,278
Kentucky Block Coal Co.	Harlan	L. & N.		Harlan	135,000
Harlan Gas Coal Co.	Harlan	L. & N.	Electric	Harlan	117,750
Kitts Creek Coal Co	Harlan	L. & N.	Pick	Harlan	work'd out
Clover Fork Coal Co.	Kitts	L. & N.	Electric	Harlan	151,620
Rex Harlan Coal Co.	Kitts	L. & N.	Electric	Harlan	38,374
Golden Ash Coal Co.	Kitts	L. & N.	Electric	Harlan	68,495
Harlan Fox Coal Co.	Black Joe	L. & N.	Electric	Harlan	31,962
Melcroft Coal Corp.	Coxton	L. & N.	Electric	Harlan	300,000
Harlan Collieries Co.	Ages	L. & N.	Electric	Harlan	153,000
High Point Coal Co.	Ages	L. & N.		Harlan	600,000

TABLE SHOWING COAL OPERATORS IN THE MIDDLESBORO BASIN—Continued.
Mines in Harlan County.—Continued.

Name	P. O.	R. R.	Equipment	Coal Bed	Annual Output (Tons)
Gem Harlan Coal Co.	Ages	L. & N.	Electric	Harlan	75,000
Verda Harlan Coal Co.	Verda	L. & N.	Pick	Harlan	6,100
King Harlan Coal Co.	Kildav	L. & N.	Electric	Harlan	160,922
J. L. Smith Coal Co.	Dildar	L. & N.	Electric	Harlan	51,626
Middleton Coal Co.	Harlan	L. & N.	Electric	Harlan	5,100
Sugar Camp Coal Co.	Evarts	L. & N.	Electric	Harlan	5,500
Darby Harlan Coal Co.	Evarts	L. & N.	Electric	Harlan	13,408
Black Mountain Corp.	Kenvir	L. & N.	Electric	Darby	340,469
Evarts Coal Co.	Evarts	L. & N.	Electric	Harlan	23,854
Superior Harlan Coal Co.	Evarts	L. & N.	Electric	Harlan	18,320
R. L. Brown C. & C. Co.	Evarts	L. & N.		Kellioka	75,000
Harlan Kellioka Coal Co	Evarts	L. & N.	Electric	Harlan	42,378
Miller & Sharp Coal Co.	Le Junior	L. & N.		Harlan	45,000
Cook & Sharp	Le Junior	L. & N.	Electric	Harlan	35,709
Berger Coal Co.	Le Junior	L. & N.	Electric	Harlan	58,865
P. V. & K. Coal Co.	Le Junior	L. & N.	Electric	Harlan	110,879
Model Coal Co.	Le Junior	L. & N.	Electric	Harlan	18,343
Benito Coal Co.	Harlan	L. & N.	Electric	Harlan	18,612
Harlan C. & C. Co.	High Splint	L. & N.	Electric	Harlan	41,000
High Splint Coal Co.	High Splint	L. & N.	Electric	High Splint	128,068
Lewis Cornet Coal Co.	Louellen	L. & N.		Harlan and High Splint	450,000
Harlan Cumberland Coal Mining Co.	Totz	L. & N.	Electric	Harlan	19,192
Looney Creek Coal Co.	PeeVee	L. & N.	Electric	Harlan	66,800
Wisconsin Steel Co.	Benham	L. & N.	Electric	"C"	900,000
U. S. Coal & Coke Co.	Lynch	L. & N.	Electric	"C"	1,780,045
Mahan Elison Coal Co.	Ligget	L. & N.		Harlan	255,000
Southern Mining Co.	Black Snake	L. & N.		Harlan	180,000
Meadows-Harlan Coal Co.	Creech	L. & N.	Pick	Harlan	13,638

TABLE OF ANALYSES OF COAL SAMPLES FROM IN AND NEAR THE MIDDLESBORO BASIN, KENTUCKY

All data in form "A," as received. Laboratory numbers are of U. S. Bureau of Mines unless otherwise stated. See Reference 14 in Bibliography.

Coal Bed	Name and Loation of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value: Calories	Heating Value: B. T. U.
Imboden	J. H. Mullin mine, 3 miles southwest of Flatgap, Virginia.	Chas. Butts	15173	2.6	3.97	31.77	53.07	11.19	.97	7,140	12,285
Imboden	Outcrop, Oven Fork of Frank's Creek, Letcher Co.		G3711 Ky. Sur.	.4	1.5	34.0	56.1	8.4	1.3	7,900	14,220
Imboden	Mine No. 2 (Hale), Stonega Coke and Coal Co. at Imboden, Wise Co., Va.	J. Brian Eby	75972	1.3	2.8	34.4	58.2	4.6	.88	7,810	14,060
Imboden	Mine No. 2 (Hale), Stonega Coke and Coal Co. at Imboden, Wise Co., Va.	J. Brian Eby	75975	1.1	2.6	34.1	58.4	4.90	.88	7,770	13,980
Imboden	Mine No. 3, Stonega Coke & Coal Co., Stonega, Va.	C. K. Wentworth	33186	1.3	2.4	33.6	53.5	10.4	.81	7,390	13,310
Imboden	Mine No. 3, Stonega Coke & Coal Co., Stonega, Va.	C. K. Wentworth	33187	.9	2.0	35.0	57.7	5.3	.69	7,915	14,250
Imboden	No. 2, Rock Heading, Stonega Coke & Coal Co., Arno, Virginia.	J. Brian Eby	75964	.7	2.1	33.0	57.8	7.1	.63	7,500	13,500
Imboden	No. 2 mine, Virginia Iron, Coal & Coke Co., Inman, Virginia.	J. Brian Eby	75969	1.2	2.5	35.7	56.2	5.6	.74	7,710	13,880
Kelly	Mine No. 2, Mohawk Coal Co., Keokee, Virginia.	Albert W. Giles	75747	1.2	2.9	36.0	54.6	6.5	.88	7,560	13,610
Kelly	Mine No. 1, Mohawk Coal Co., Keokee, Virginia.	Albert W. Giles	75748	1.8	3.4	35.2	54.8	6.6	.77	7,490	13,490
Kelly	Mine No. 1, Mohawk Coal Co., Keokee, Virginia.	Albert W. Giles	75749	1.5	3.3	35.1	55.1	6.53	.84	7,530	13,560
Lower St. Charles (No. 2)	Local mine, ½ mile east of mouth of Big Branch of Straight Creek, Lee Co., Va.	Albert W. Giles	75909	0.7	2.8	38.0	53.5	5.7	2.06	7,530	13,550
Upper St. Charles (No. 2A)	Local mine, ½ mile east of Straight Creek on Big Branch, Lee Co., Va.	Albert W. Giles	75908	0.7	3.6	31.9	53.1	11.4	.61	6,960	12,530
Upper St. Charles (No. 2A)	Local mine at St. Charles, Virginia.	Albert W. Giles	75906	0.8	3.3	33.1	53.7	9.9	.62	7,145	12,860
Harlan	Outcrop, Oven Fork of Frank's Creek, Letcher Co.		G3710 Ky. Sur.	0.4	1.4	36.3	57.5	4.8	.9	7,417	13,350
Lower Standiford	Local mine, 1½ miles south of Flat Gap, Virginia.	Chas. Butts	15172	2.8	4.07	35.21	55.69	5.03	1.74	7,725	13,905
Harlan	Clover Fork mine, 2 miles east of Harlan.	E. B. Sutton	24728	0.4	2.02	39 25	55.63	3.10	.78	7,986	14,375
Harlan	Clover Fork mine, 2 miles east of Harlan.	E. B. Sutton	24729	2.1	3.83	37.11	56.56	2.50	.67	7,900	14,220
Harlan	Clover Fork mine, 2 miles east of Harlan.	E. B. Sutton	24730	1.7	3.40	37.41	56.49	2.70	.82	7,912	14,242
Harlan	Clover Fork mine, 2 miles east of Harlan.	E. B. Sutton	24731	1.7	3.35	37.46	56.19	3.00	.61	7,878	14,180
Harlan	Clover Fork mine. Composite of three preceding samples.	E. B. Sutton	24732	1.8	3.56	37.18	56.55	2.71	.70	7,900	14,220
Harlan	Coxton mine, 4 miles east of Harlan.	E. B. Sutton	24713	2.0	3.68	36.42	56.23	3.67	1.30	7,814	14,065
Harlan	Coxton mine, 4 miles east of Harlan.	E. B. Sutton	24714	1.5	2.76	37.95	55.79	3.50	.83	7,882	14,188
Harlan	Coxton mine, 4 miles east of Harlan.	E. B. Sutton	24715	1.8	3.04	37.02	56.60	3.34	.87	7,868	14,162
Harlan	Coxton mine, 4 miles east of Harlan.	E. B. Sutton	24716	1.3	3.03	36.91	57.10	2.96	.70	7,932	14,278
Harlan	Coxton mine. Composite of four preceding samples.	E. B. Sutton	24717	1 6	3.18	37.21	56.30	3.31	.93	7,859	14,146
Harlan	Gaston mine, 1 mile east of Harlan.	E. B. Sutton	24633	1.6	3.22	37.52	56.36	2.90	.52	7,910	14,238
Harlan	Gaston mine, 1 mile east of Harlan.	E. B. Sutton	24634	1.4	3.03	37.94	56.47	2.56	.60	7,962	14,332
Harlan	Gaston mine. Composite of two preceding samples.	E. B. Sutton	24635	1.5	3.29	37.86	56.17	2.68	.57	7,950	14,310
Harlan	Wood mine, 3 miles east of Harlan.	E. B. Sutton	24770	1.1	3.13	35.66	55.47	5.74	1.35	7,616	13,709
Harlan	Wood mine, 3 miles east of Harlan.	E. B. Sutton	24771	1.7	3.90	35.98	55.92	4.20	.61	7,735	13,923

TABLE OF ANALYSES OF COAL SAMPLES FROM IN AND NEAR THE MIDDLESBORO BASIN, KENTUCKY—Continued.

Coal Bed	Name and Location of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value: Calories	Heating Value: B. T. U.
Harlan	Wood mine, 3 miles east of Harlan.	E. B. Sutton	24772	1.5	3.44	36.18	54.80	5.58	.71	7,631	13,736
Harlan	Wood mine. Composite of two preceding samples.	E. B. Sutton	24773	1.6	3.59	35.99	55.45	4.97	.70	7,679	13,822
Harlan	Cardinal mine, Cardinal, Kentucky.	U. S. Bureau of Mines	81407	0.8	1.9	38.5	56.4	3.2	1.00	7,856	14,140
Harlan	Cardinal mine, Cardinal, Kentucky.	U. S. Bureau of Mines	81408	1.4	2.6	37.8	55.9	3.7	.90	7,800	14,040
Harlan	Cardinal mine, Cardinal, Kentucky.	U. S. Bureau of Mines	81409	1.0	3.1	37.4	56.2	4.3	.90	7,722	13,900
Harlan	Cardinal mine, Cardinal, Kentucky.	U. S. Bureau of Mines	81410	0.7	1.8	38.6	55.4	4.2	.90	7,806	14,050
Harlan	Cardinal mine. Composite of four preceding samples.	U. S. Bureau of Mines	81411	1.0	2.1	38.3	55.9	3.7	.80	7,817	14,070
Harlan	Brookside mine, Ages, Ky.	U. S. Bureau of Mines	81528	1.5	3.1	36.9	56.1	3.9	.8	7,756	13,960
Harlan	Brookside mine, Ages, Ky.	U. S. Bureau of Mines	81529	1.3	2.8	37.2	56.0	4.0	1.1	7,717	13,890
Harlan	Brookside mine, Ages, Ky.	U. S. Bureau of Mines	81530	1.1	2.6	37.8	55.8	3.8	.9	7,828	14,090
Harlan	Brookside mine, Ages, Ky.	U. S. Bureau of Mines	81531	1.5	2.9	36.4	56.7	4.0	.9	7,750	13,950
Harlan	Brookside mine, Ages, Ky.	U. S. Bureau of Mines	81532	1.0	2.4	36.5	55.2	5.9	1.4	7,655	13,780
Harlan	Brookside mine. Composite of five preceding samples.	U. S. Bureau of Mines	81533	1.3	2.8	37.0	55.9	4.3	1.1	7,750	13,950
Harlan	Crown By-product mine, Chevrolet, Kentucky.	U. S. Bureau of Mines	81893	1.5	2.5	36.7	56.9	3.9	.7	7,794	14,030
Harlan	Crown By-product mine, Chevrolet, Kentucky.	U. S. Bureau of Mines	81894	1.5	2.5	37.6	56.5	3.4	.8	7,894	14,210
Harlan	Crown By-product mine, Chevrolet, Kentucky.	U. S. Bureau of Mines	81895	1.5	2.5	37.7	56.9	2.9	.7	7,900	14,220
Harlan	Crown By-product mine, Chevrolet, Kentucky.	U. S. Bureau of Mines	81896	1.8	2.7	36.8	57.2	3.3	.8	7,856	14,144
Harlan	Crown By-product mine, Chevrolet, Kentucky.	U. S. Bureau of Mines	81897	1.6	2.6	36.7	56.9	3.8	.8	7,850	14,130

Coal Bed	Name and Location of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value: Calories	Heating Value: B. T. U.
Harlan	Crown By-product mine, Chevrolet, Kentucky.	U. S. Bureau of Mines	81898	1.6	2.6	36.6	57.0	3.8	.9	7,817	14,070
Harlan	Crown By-product mine. Composite of six preceding samples.	U. S. Bureau of Mines	81899	1.6	2.6	36.6	57.3	3.5	.8	7,850	14,130
Harlan	Mary Helen mine, Coalgood, Kentucky.	U. S. Bureau of Mines	81739	1.9	2.2	37.2	56.7	2.9	.9	7,817	14,070
Harlan	Mary Helen mine, Coalgood, Kentucky.	U. S. Bureau of Mines	81740	1.4	2.7	36.8	56.5	4.0	9.	7,794	14,030
Harlan	Mary Helen mine, Coalgood, Kentucky.	U. S. Bureau of Mines	81741	1.5	2.9	37.7	56.6	2.8	.8	7,883	14,190
Harlan	Mary Helen mine, Coalgood, Kentucky.	U. S. Bureau of Mines	81742	1.3	3.0	38.0	55.8	3.2	.9	7,872	14,170
Harlan	Mary Helen mine, Coalgood, Kentucky.	U. S. Bureau of Mines	81743	1.4	3.1	37.2	56.7	3.0	.9	7,861	14,150
Harlan	Mary Helen mine, Coalgood, Kentucky.	U. S. Bureau of Mines	81744	1.3	2.9	37.4	56.3	3.4	.8	7,828	14,090
Harlan	Mary Helen mine. Composite of six preceding samples.	U. S. Bureau of Mines	81745	1.4	2.9	37.5	56.2	3.4	.9	7,833	14,100
Harlan	Kayn mine, Coxton, Ky.	U. S. Bureau of Mines	81523	1.3	2.7	37.7	56.2	3.4	.8	7,822	14,080
Harlan	Kayn mine, Coxton, Ky.	U. S. Bureau of Mines	81524	1.2	2.8	36.9	56.8	3.5	.9	7,789	14,020
Harlan	Kayn mine, Coxton, Ky.	U. S. Bureau of Mines	81525	2.0	3.5	35.6	57.1	3.8	.8	7,683	13,830
Harlan	Kayn mine, Coxton, Ky.	U. S. Bureau of Mines	81526	1.2	2.9	36.8	55.5	4.8	.7	7,633	13,740
Harlan	Kayn mine. Composite of four preceding samples.	U. S. Bureau of Mines	81527	1.4	3.0	36.7	56.4	3.9	.9	7,750	13,950
Harlan	R. C. Tway mine.	U. S. Bureau of Mines	82061	1.7	2.7	37.7	57.1	2.5	.7	7,956	14,320
Harlan	R. C. Tway mine.	U. S. Bureau of Mines	82062	1.7	2.6	36.9	57.5	3.0	.7	7,917	14,250
Harlan	R. C. Tway mine.	U. S. Bureau of Mines	82063	1.7	2.7	37.0	55.9	4.4	.7	7,789	14,020
Harlan	R. C. Tway mine.	U. S. Bureau of Mines	82064	1.7	2.7	36.7	57.8	2.8	.7	7,920	14,220
Harlan	R. C. Tway mine.	U. S. Bureau of Mines	82065	1.8	2.7	37.0	56.9	3.4	.7	7,894	14,210
Harlan	R. C. Tway mine. Composite of five preceding samples.	U. S. Bureau of Mines	82066	1.7	2.8	37.4	56.6	3.2	.7	7,872	14,170
Harlan	Harlan No. 1 mine, High Splint, Kentucky.	U. S. Bureau of Mines	81753	1.7	2.8	37.3	52.6	7.3	1.1	7,472	13,450
Harlan	Harlan No. 1 mine, High Splint, Kentucky.	U. S. Bureau of Mines	81694	1.2	2.8	37.5	54.6	5.1	1.2	7,722	13,900
Harlan	Harlan No. 1 mine, High Splint, Kentucky.	U. S. Bureau of Mines	81695	1.0	2.6	36.7	55.6	5.1	1.2	7,611	13,700
Harlan	Harlan No. 1 mine, High Splint, Kentucky.	U. S. Bureau of Mines	81696	1.0	2.7	37.9	54.3	5.1	1.1	7,733	13,920
Harlan	Harlan No. 1 mine. Composite of four preceding samples.	U. S. Bureau of Mines	81697	1.2	2.9	37.2	53.9	6.0	1.2	7,617	13,710

TABLE OF ANALYSES OF COAL SAMPLES FROM IN AND NEAR THE MIDDLESBORO BASIN, KENTUCKY—Continued.

Coal Bed	Name and Location of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value: Calories	Heating Value: B. T. U.
Harlan	Harlan No. 1 mine, High Splint, Kentucky.	U. S. Bureau of Mines	81699	2.7	4.7	35.7	51.5	8.1	.8	7,133	12,840
Harlan	Harlan No. 1 mine, High Splint, Kentucky.	U. S. Bureau of Mines	81700	3.0	5.0	36.0	53.9	5.1	.7	7,372	13,270
Harlan	Harlan No. 1 mine, High Splint, Kentucky.	U. S. Bureau of Mines	81701	2.7	4.7	36.4	54.2	4.7	.7	7,422	13,360
Harlan	Harlan No. 1 mine. Composite of three preceding samples.	U. S. Bureau of Mines	81702	2.7	4.8	35.8	53.4	6.0	.7	7,317	13,170
Harlan	Golden Ash mine, Kitts, Kentucky.	U. S. Bureau of Mines	81518	2.2	3.9	36.5	56.0	3.6	.8	7,728	13,910
Harlan	Golden Ash mine, Kitts, Kentucky.	U. S. Bureau of Mines	81519	2.3	3.9	37.3	53.1	5.6	.7	7,489	13,480
Harlan	Golden Ash mine, Kitts, Kentucky.	U. S. Bureau of Mines	81520	1.6	3.1	36.9	57.3	2.7	.7	7,867	14,160
Harlan	Golden Ash mine, Kitts, Kentucky.	U. S. Bureau of Mines	81521	1.6	3.1	37.1	56.3	3.5	.6	7,822	14,080
Harlan	Golden Ash mine. Composite of four preceding samples.	U. S. Bureau of Mines	81522	1.9	3.5	36.6	56.1	3.8	.8	7,705	13,870
Harlan	Rex mine, Kitts, Ky.	U. S. Bureau of Mines	81513	1.2	3.0	36.8	57.2	3.0	.8	7,878	14,180
Harlan	Rex mine, Kitts, Ky.	U. S. Bureau of Mines	81514	1.5	3.3	36.4	58.0	2.3	1.0	7,867	14,160
Harlan	Rex mine, Kitts, Ky.	U. S. Bureau of Mines	81515	1.4	3.0	37.2	57.3	2.5	.7	7,911	14,240
Harlan	Rex mine, Kitts, Ky.	U. S. Bureau of Mines	81516	1.5	3.1	36.9	56.7	3.3	.8	7,806	14,050
Harlan	Rex mine. Composite of four preceding samples.	U. S. Bureau of Mines	81517	1.4	3.1	37.1	57.0	2.8	.8	7,878	14,180
Harlan	Mahan-Ellison mine, Liggett, Kentucky.	U. S. Bureau of Mines	81729	1.5	3.6	35.5	57.3	3.6	.9	7,789	14,020
Harlan	Mahan-Ellison mine, Liggett, Kentucky.	U. S. Bureau of Mines	81730	1.7	3.4	35.0	56.6	5.0	.9	7,622	13,720

Harlan	Mahan-Ellison mine, Liggett, Kentucky.	U. S. Bureau of Mines	81731	1.5	3.4	35.2	57.8	3.6	.8	7,767	13,980
Harlan	Mahan-Ellison mine. Composite of three preceding samples.	U. S. Bureau of Mines	81732	1.6	3.4	35.1	57.5	4.0	.8	7,722	13,900
Harlan	Perkins-Harlan No. 1 mine, Liggett, Kentucky.	U. S. Bureau of Mines	81703	2.1	3.6	37.0	56.7	2.7	.7	7,800	14,040
Harlan	Perkins-Harlan No. 1 mine, Liggett, Kentucky.	U. S. Bureau of Mines	81704	3.1	4.5	36.2	57.3	2.0	.7	7,811	14,060
Harlan	Perkins-Harlan No. 1 mine, Liggett, Kentucky.	U. S. Bureau of Mines	81705	2.0	3.3	38.7	57.0	2.0	.7	7,878	14,180
Harlan	Perkins-Harlan No. 1 mine, Liggett, Kentucky.	U. S. Bureau of Mines	81706	1.8	3.2	37.0	57.2	2.6	.8	7,861	14,150
Harlan	Perkins-Harlan No. 1 mine. Composite of four preceding samples.	U. S. Bureau of Mines	81707	2.2	3.7	36.9	57.0	2.4	.8	7,828	14,090
Harlan	Berger No. 1 mine, Lejunior, Kentucky.	U. S. Bureau of Mines	81688	1.3	3.0	36.2	55.6	5.2	1.2	7,694	13,850
Harlan	Berger No. 1 mine, Lejunior, Kentucky.	U. S. Bureau of Mines	81689	1.1	2.8	37.2	54.1	5.9	1.3	7,644	13,760
Harlan	Berger No. 1 mine, Lejunior, Kentucky.	U. S. Bureau of Mines	81690	.9	2.7	37.6	53.8	5.9	1.2	7,650	13,770
Harlan	Berger No. 1 mine, Lejunior, Kentucky.	U. S. Bureau of Mines	81691	1.5	3.3	35.6	54.9	6.2	1.0	7,539	13,570
Harlan	Berger No. 1 mine. Composite of four preceding samples.	U. S. Bureau of Mines	81692	2.2	3.0	36.3	55.0	5.7	1.1	7,617	13,710
Upper Hance	Varilla mine, Varilla, Ky.	G. T. Powell	21776	1.1	2.53	37.64	56.29	3.54	1.06	7,918	14,252
Upper Hance	Varilla mine, Varilla, Ky.	G. T. Powell	21777	.9	2.25	38.13	55.09	4.53	1.55	7,840	14,112
Upper Hance	Varilla mine, Varilla, Ky.	G. T. Powell	21778	.8	2.04	39.06	52.37	6.53	2.65	7,695	13,851
Upper Hance	Varilla mine, Varilla, Ky.	G. T. Powell	21779	.9	2.32	37.37	56.37	3.94	1.03	7,880	14,184
Upper Hance	Varilla mine. Composite of four preceding samples.	G. T. Powell	21780	.9	2.34	37.82	55.24	4.60	1.57	7,840	14,112
Taggart	Benham Mine, Benham, Ky.	E. B. Sutton	24834	.8	2.64	36.83	58.45	2.08	.53	8,102	14,584
Taggart	Benham Mine, Benham, Ky.	E. B. Sutton	24835	.6	2.59	37.25	58.37	1.79	.51	8,124	14,623
Taggart	Benham Mine, Benham, Ky.	E. B. Sutton	24836	.8	2.74	36.99	58.12	2.15	.48	8,093	14,567
Taggart	Benham Mine, Benham, Ky.	E. B. Sutton	24837	.7	2.60	37.80	56.74	2.86	.32	8,047	14,485
Taggart	Benham mine. Composite of four preceding samples.	E. B. Sutton	24838	.7	2.50	37.52	57.63	2.35	.52	8,105	14,589
Taggart	"Harlan" Cooperative No. 1 mine, Evarts, Ky.	U. S. Bureau of Mines	81534	2.2	3.9	37.8	54.1	4.2	.8	7,622	13,720
Taggart	"Harlan" Cooperative No. 1 mine, Evarts, Ky.	U. S. Bureau of Mines	81535	1.0	2.9	36.5	57.3	3.3	.7	7,822	14,080
Taggart	"Harlan" Cooperative No. 1 mine, Evarts, Ky.	U. S. Bureau of Mines	81536	1.3	3.0	37.3	56.3	3.4	.8	7,761	13,970

TABLE OF ANALYSES OF COAL SAMPLES FROM IN AND NEAR THE MIDDLESBORO BASIN, KENTUCKY—Continued.

Coal Bed	Name and Location of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value	
										Calories	B. T. U.
Taggart	"Harlan" Cooperative No. 1 mine, Evarts, Ky.	U. S. Bureau of Mines	81537	1.3	2.9	38.0	55.8	3.3	.7	7,817	14,070
Taggart	"Harlan" Cooperative No. 1 mine. Composite of four preceding samples.	U. S. Bureau of Mines	81538	1.5	3.2	36.6	56.6	3.6	.7	7,772	13,990
Taggart	Outcrop, near head of Frank's Creek, Letcher Co.		G3709 Ky. Sur.	.5	1.4	36.8	56.4	5.4	.7	7,983	14,370
Taggart	Mine No. 1, Virginia Lee Co., St. Charles, Va.	Albert W. Giles	34980	.7	2.8	37.0	56.9	3.33	.53	7,740	13,930
Taggart	Mine No. 3, Old Virginia Coal Co., St. Charles, Va.	Albert W. Giles	75793	1.5	3.8	37.7	56.3	2.2	.76	7,815	14,070
Taggart	Mine No. 1, Stonega, Coke & Coal Co., Keokee, Va.	Albert W. Giles	75680	1.3	3.2	34.7	57.5	4.57	.74	7,735	13,930
Taggart	Kirk mine, Wilma Coal Co., St. Charles, Va.	W. A. Forrester	82422	2.1	3.6	36.7	57.6	2.06	.48	7,840	14,110
Taggart	No. 3 mine of Bondurant, United Collieries, Inc., St. Charles, Va.	W. A. Forrester	82426	2.0	3.8	36.6	57.5	2.1	.43	7,805	14,050
Taggart	Darby mine of United Mining Co., Darbyville, Va.	W. A. Forrester	82436	1.4	3.4	37.2	57.3	2.1	.45	7,820	14,080
Taggart	Mine No. 3 of the Stonega Coke and Coal Co., Roda, Virginia.	C. K. Wentworth	33204	.8	2.0	35.2	60.4	2.4	.50	8,165	14,700
Taggart	Mine No. 3 of the Stonega Coke and Coal Co., Roda, Virginia.	C. K. Wentworth	33207	.8	2.1	34.9	60.9	2.18	.54	8,160	14,690
Mason	Armu mine, Colmar, Ky.	G. T. Powell	21681	.8	2.28	38.59	54.46	4.67	1.33	7,842	14,116
Mason	Armu mine, Colmar, Ky.	G. T. Powell	21682	1.0	2.48	37.93	53.53	6.06	1.73	7,696	13,853
Mason	Armu mine, Colmar, Ky.	G. T. Powell	21683	1.0	2.62	37.31	53.16	6.91	1.53	7,625	13,725

Coal Bed	Name and Location of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calories	B. T. U.
Mason	Armu mine, Colmar, Ky.	G. T. Powell	21684	.6	2.26	39.10	53.78	4.86	1.47	7,854	14,137
Mason	Armu mine. Composite of four preceding samples.	G. T. Powell	21685	.9	2.54	38.20	53.72	5.54	1.51	7,760	13,968
Mason	Tejay mine, Tejay, Ky.	G. T. Powell	21562	1.9	3.13	37.35	56.75	2.72	.85	7,884	14,191
Mason	Tejay mine, Tejay, Ky.	G. T. Powell	21563	1.1	2.81	37.76	56.29	3.14	.95	7,911	14,240
Mason	Tejay mine, Tejay, Ky.	G. T. Powell	21564	1.1	2.74	38.98	55.66	2.62	.99	7,954	14,317
Mason	Tejay mine, Tejay, Ky.	G. T. Powell	21565	1.0	2.69	38.46	54.97	3.88	.96	7,854	14,137
Mason	Tejay mine. Composite of four preceding samples.	G. T. Powell	21566	1.3	2.92	37.98	56.04	3.06	.98	7,901	14,222
Mason	Log Mountain No. 1 mine, near Chenoa, Ky.	G. T. Powell	21781	2.7	4.78	35.77	57.12	2.33	.69	7,736	13,925
Mason	Log Mountain No. 1 mine, near Chenoa, Ky.	G. T. Powell	21782	1.5	4.16	35.98	57.79	2.07	.72	7,798	14,036
Mason	Log Mountain No. 1 mine, near Chenoa, Ky.	G. T. Powell	21783	2.2	4.39	36.22	56.31	3.08	1.05	7,672	13,810
Mason	Log Mountain No. 1 mine, near Chenoa, Ky.	G. T. Powell	21784	2.1	4.45	36.00	57.36	2.19	.79	7,761	13,970
Mason	Log Mountain No. 1 mine. Composite of four preceding samples.	G. T. Powell	21785	2.1	4.35	36.11	57.12	2.42	.79	7,742	13,936
Creech	Black Mountain mine, Balkan, Kentucky.	U. S. Bureau of Mines	81399	.6	1.7	37.6	57.0	3.7	.7	7,861	14,150
Creech	Black Mountain mine, Balkan, Kentucky.	U. S. Bureau of Mines	81400	1.0	2.3	37.6	55.5	4.6	8	7,772	13,990
Creech	Black Mountain mine, Balkan, Kentucky.	U. S. Bureau of Mines	81401	.8	2.5	37.6	55.7	4.2	.8	7,783	14,010
Creech	Black Mountain mine, Balkan, Kentucky.	U. S. Bureau of Mines	81402	1.1	2.5	36.5	56.7	4.3	1.1	7,761	13,970
Creech	Black Mountain mine, Balkan, Kentucky.	U. S. Bureau of Mines	81403	1.5	2.9	36.3	54.5	6.3	1.5	7,572	13,630
Creech	Black Mountain mine, Balkan, Kentucky.	U. S. Bureau of Mines	81404	.9	2.3	37.7	56.0	4.0	.8	7,844	14,120
Creech	Black Mountain mine, Balkan, Kentucky.	U. S. Bureau of Mines	81405	1.1	2.4	37.2	56.4	4.0	1.4	7,756	13,960
Creech	Black Mountain mine. Composite of seven preceding samples.	U. S. Bureau of Mines	81406	1.0	2.6	37.2	55.8	4.4	1.1	7,777	14,000
Sandstone Parting	Shamrock mine, Shamrock, Kentucky.	U. S. Bureau of Mines	82413	1.7	2.8	35.2	54.9	7.1	1.7	7,456	13,420
Sandstone Parting	Shamrock mine, Shamrock, Kentucky.	U. S. Bureau of Mines	83414	2.3	3.5	35.3	54.2	7.0	1.0	7,417	13,500
Sandstone Parting	Shamrock mine, Shamrock, Kentucky.	U. S. Bureau of Mines	82415	1.4	2.7	35.8	54.3	7.2	.9	7,444	13,400
Sandstone Parting	Shamrock mine, Shamrock, Kentucky,	U. S. Bureau of Mines	82416	1.5	2.8	36.0	55.9	5.3	.9	7,589	13,660

TABLE OF ANALYSES OF COAL SAMPLES FROM IN AND NEAR THE MIDDLESBORO BASIN, KENTUCKY—Continued.

Coal Bed	Name and Location of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value: Calories	Heating Value: B. T. U.
Sandstone Parting Low Splint	Shamrock mine. Composite of four preceding samples.	U. S. Bureau of Mines	82417	1.8	3.1	35.1	54.9	6.9	1.0	7,478	13,460
Low Splint	Mine No. 3, Virginia Iron, Coal and Coke Co., St. Charles, Va.	Albert W. Giles	75806	1.4	3.7	35.1	54.3	6.9	1.10	7,400	13,320
Low Splint	Mine No. 3, Virginia Iron, Coal and Coke Co., St. Charles, Va.	Albert W. Giles	75807	1.1	3.3	35.2	52.1	9.4	1.02	7,105	12,790
Low Splint	Mine No. 3, Virginia Iron, Coal and Coke Co., St. Charles, Va.	Albert W. Giles	75808	1.2	3.5	35.2	53.3	8.05	1.10	7,260	13,070
Phillips	Mine No. 1, Benedict Coal Corp., St. Charles, Va.	Albert W. Giles	75789	1.5	3.8	36.6	53.2	6.4	.77	7,405	13,330
Phillips	Mine No. 1, Benedict Coal Corp., St. Charles, Va.	Albert W. Giles	75790	1.2	3.7	35.4	52.0	9.9	.72	7,080	12,740
Phillips	Mine No. 1, Benedict Coal Corp., St. Charles, Va.	Albert W. Giles	75791	1.4	3.8	35.5	52.7	8.04	.80	7,235	13,020
Wallins	Creech No. 1 mine, Twila, Kentucky.	U. S. Bureau of Mines	81900	1.9	2.7	40.4	53.9	3.0	.7	7,694	13,850
Wallins	Creech No. 1 mine, Twila, Kentucky.	U. S. Bureau of Mines	81901	2.2	3.4	39.0	54.2	3.4	.7	7,669	13,800
Wallins	Creech No. 1 mine, Twila, Kentucky.	U. S. Bureau of Mines	81902	2.4	3.1	37.8	55.1	4.0	.8	7,611	13,700
Wallins	Creech No. 1 mine, Twila, Kentucky.	U. S. Bureau of Mines	81903	2.6	3.5	38.1	55.3	3.1	.6	7,672	13,810
Wallins	Creech No. 1 mine, Twila, Kentucky.	U. S. Bureau of Mines	81904	2.1	3.3	38.7	54.7	3.3	.8	7,711	13,880
Wallins	Creech No. 1 mine, Twila, Kentucky.	U. S. Bureau of Mines	81905	2.1	3.4	39.0	54.2	3.4	.8	7,667	13,800
Wallins	Creech No. 1 mine, Twila, Kentucky.	U. S. Bureau of Mines	81906	2.2	3.3	39.1	54.3	3.3	.7	7,678	13,820

Coal Bed	Name and Location of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value: Calories	Heating Value: B. T. U.
Wallins	Creech No. 2 mine, Twila, Kentucky.	U. S. Bureau of Mines	82056	1.8	2.9	38.0	53.6	5.5	1.0	7,494	13,490
Wallins	Creech No. 2 mine, Twila, Kentucky.	U. S. Bureau of Mines	82057	1.7	3.0	39.0	53.7	4.3	1.0	7,633	13,740
Wallins	Creech No. 2 mine, Twila, Kentucky.	U. S. Bureau of Mines	82058	1.9	3.0	38.4	53.7	4.9	1.0	7,578	13,640
Wallins	Creech No. 2 mine, Twila, Kentucky.	U. S. Bureau of Mines	82059	1.8	3.0	38 0	54.3	4.7	.9	7,600	13,680
Wallins	Creech No. 2 mine. Composite of four preceding samples.	U. S. Bureau of Mines	82060	1.8	3.1	37.7	54.4	4.8	1.0	7,583	13,650
Poplar Lick	Log Mountain No. 52 mine, Harrison, Kentucky.	G. T. Powell	21617	1.0	3.33	37.04	53.63	6.0	1.06	7,545	13,581
Poplar Lick	Log Mountain No. 52 mine, Harrison, Kentucky.	G. T. Powell	21618	1.1	3.35	37.83	54.44	4.38	.96	7,679	13,822
Poplar Lick	Log Mountain No. 52 mine, Harrison, Kentucky.	G. T. Powell	21619	1.2	3.58	36.81	54.40	5.21	.96	7,577	13,639
Poplar Lick	Log Mountain No. 52 mine, Harrison, Kentucky.	G. T. Powell	21620	1.3	3.54	37.70	53.90	4.06	1.08	7,623	13,721
Poplar Lick	Log Mountain No. 52 mine, Composite of four preceding samples.	G. T. Powell	21621	1.2	3.37	37.52	54.03	5.08	1.01	7,616	13,709
Poplar Lick	Pinnacle mine, Ralston, Ky.	U. S. Bureau of Mines	82072	1.9	2.8	39.0	49.3	8.9	3.0	7,283	13,110
Poplar Lick	Pinnacle mine, Ralston, Ky.	U. S. Bureau of Mines	82073	2.1	3.1	37.6	50.0	9.3	2.9	7,222	13,000
Poplar Lick	Pinnacle mine, Ralston, Ky.	U. S. Bureau of Mines	82074	3.4	3.3	38.5	49.9	8.3	2.3	7,300	13,140
Poplar Lick	Pinnacle mine, Ralston, Ky.	U. S. Bureau of Mines	82075	2.1	3.1	38.5	50.4	8.0	3.2	7,350	13,230
Poplar Lick	Pinnacle mine. Composite of four preceding samples.	U. S. Bureau of Mines	82076	2.1	3.0	37.9	50.5	8.6	2 8	7,283	13,110
Poplar Lick	Crystal mine, Logmont, Ky.	U. S. Bureau of Mines	82067	1.7	2.7	37.9	50.9	8.5	2.8	7,356	13,240
Poplar Lick	Crystal mine, Logmont, Ky.	U. S. Bureau of Mines	82068	1.8	2.9	36.6	48.0	12.5	2.6	6,967	12,540
Poplar Lick	Crystal mine, Logmont, Ky.	U. S. Bureau of Mines	82069	1.8	2.8	37.0	49.0	11.12	2.6	7,111	12,800
Poplar Lick	Crystal mine, Logmont, Ky.	U. S. Bureau of Mines	82070	2.1	3.0	37.4	49.3	10.3	2.3	7,106	12,790
Poplar Lick	Crystal mine. Composite of four preceding samples.	U. S. Bureau of Mines	82071	1.8	2.8	36.7	49.9	10.6	2.6	7,144	12,860
Pardee	Pardee No. 1 mine, Blackwood Coal and Coke Co., Pardee, Wise Co., Va.	J. Brian Eby	84361	1.6	2.4	35.7	55.8	6.1	.90	7,680	13,830
Pardee	Pardee No. 4 mine, Pardee.	J. Brian Eby	84364	4.3	5.1	32.5	56.4	6.0	.80	7,345	13,210
Pardee	Pardee mine, Pardee, Va. Mine extends into Ky.		G3707 Ky. Sur.	.2	1.3	36.4	58.0	4.3	.7	8,222	14,800
Pardee	Pardee mine, Pardee, Va. Mine extends into Ky.	J. Brian Eby	G3708 Ky. Sur.	.3	1.3	35.6	56.7	6.4	1.1	7,839	14,110
Smith	Mill Creek mine, Grays Knob, Kentucky.	U. S. Bureau of Mines	81693	1.7	4.0	34.3	54.0	7.7	1.1	7,228	13,010

TABLE OF ANALYSES OF COAL SAMPLES FROM IN AND NEAR THE MIDDLESBORO BASIN, KENTUCKY—Continued.

Coal Bed	Name and Location of Mine	Collector	Laboratory No.	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Value	
										Calories	B. T. U.
Smith	Mill Creek mine, Grays Knob, Kentucky.	U. S. Bureau of Mines	81733	1.8	4.0	35.2	52.6	8.2	1.1	7,183	12,930
Smith	Mill Creek mine, Grays Knob, Kentucky.	U. S. Bureau of Mines	81734	1.9	4.1	35.8	52.1	8.0	1.0	7,161	12,890
Smith	Mill Creek mine, Grays Knob, Kentucky.	U. S. Bureau of Mines	81735	2.3	4.2	35.3	51.8	8.7	.9	7,089	12,760
Smith	Mill Creek mine, Grays Knob, Kentucky.	U. S. Bureau of Mines	81736	2.1	3.9	33.7	53.9	8.5	.9	7,144	12,860
Smith	Mill Creek mine, Grays Knob, Kentucky.	U. S. Bureau of Mines	81737	2.7	4.4	35.1	53.5	7.0	.8	7,233	13,020
Smith	Mill Creek mine. Composite of six preceding samples.	U. S. Bureau of Mines	81738	2.1	4.0	34.5	53.4	8.1	.9	7,161	12,890
High Splint	High Splint mine, High Splint, Kentucky.		81698	1.2	2.9	37.2	53.9	6.0	1.2	7,617	13,710
High Splint	Prospect pit, Big Black Mountain, Harlan Co.	J. S. Burrows	2271	2.1	4.45	36.27	56.05	3.23	.54		
High Splint	Prospect pit, Big Black Mountain, Harlan Co.	J. S. Burrows	2272	2.5	4.72	35.74	57.06	2.48	.54		
High Splint	Prospect pit. Weathered sample.	J. S. Burrows	2270	2.2	4.32	36.04	57.36	2.28	.48	7,845	14,121
High Splint	Local mine, Gin Creek, Darbyville, Virginia.	C. A. Fisher	6239	3.1	5.5	36.0	51.9	6.61	1.24	7,285	13,110
Lower Hignite	Chenoa Hignite mine, Chenoa, Kentucky.	G. T. Powell	21786	1.2	3.24	36.61	53.69	6.46	1.45	7,424	13,363
Lower Hignite	Chenoa Hignite mine, Chenoa, Kentucky.	G. T. Powell	21787	6.1	8.37	35.73	51.64	4.26	.97	7,242	13,036
Lower Hignite	Chenoa Hignite mine, Chenoa, Kentucky.	G. T. Powell	21788	2.3	4.64	36.98	54.07	4.31	1.02	7,559	13,606
Lower Hignite	Chenoa Hignite mine, Chenoa, Kentucky.	G. T. Powell	21789	2.1	4.43	36.90	54.32	4.35	1.11	7,543	13,577

Lower Hignite	Chenoa Hignite mine. Composite of three preceding samples.	G. T. Powell	21790	3.5	5.74	36.76	53.20	4.30	1.01	7,446	13,403
Hignite	Atlas mine, Ralston, Ky.	U. S. Bureau of Mines	82403	2.1	3.2	37.0	55.9	3.9	.6	7,711	13,880
Hignite	Atlas mine, Ralston, Ky.	U. S. Bureau of Mines	82404	3.0	3.9	36.6	55.7	3.8	.6	7,650	13,770
Hignite	Atlas mine, Ralston, Ky.	U. S. Bureau of Mines	82405	2.5	3.6	36.9	55.6	3.9	.7	7,628	13,730
Hignite	Atlas mine, Ralston, Ky.	U. S. Bureau of Mines	82406	2.8	3.9	34.8	55.9	5.4	.7	7,522	13,540
Hignite	Atlas mine. Composite of four preceding samples.	U. S. Bureau of Mines	82407	2.6	3.7	36.4	55.7	4.2	.7	7,628	13,730
Sterling	Edgewood No. 2 mine, Shamrock, Virginia.	U. S. Bureau of Mines	82408	1.6	2.4	37.8	50.4	9.4	3.2	7,244	13,040
Sterling	Edgewood No. 2 mine, Shamrock, Virginia.	U. S. Bureau of Mines	82409	1.5	2.2	37.0	51.0	9.8	3.1	7,300	13,140
Sterling	Edgewood No. 2 mine, Shamrock, Virginia.	U. S. Bureau of Mines	82410	1.6	2.3	36.6	51.3	9.8	2.7	7,261	13,070
Sterling	Edgewood No. 2 mine, Shamrock, Virginia.	U. S. Bureau of Mines	82411	1.1	2.1	37.6	51.3	9.0	3.2	7,361	13,250
Sterling	Edgewood No. 2 mine. Composite of four preceding samples.	U. S. Bureau of Mines	82412	1.4	2.3	36.7	51.6	9.4	3.1	7,306	13,150

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